S. HRG. 107–340

"LEAP AHEAD" TECHNOLOGIES AND TRANSFORMATION INITIATIVES WITHIN THE DEFENSE SCIENCE AND TECHNOLOGY PROGRAM

HEARING

BEFORE THE

SUBCOMMITTEE ON EMERGING THREATS AND CAPABILITIES

OF THE

COMMITTEE ON ARMED SERVICES
UNITED STATES SENATE

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CONTENTS

CHRONOLOGICAL LIST OF WITNESSES

"Leap Ahead" Technologies and Transformation Initiatives Within the Defense Science and Technology Program

June 5, 2001

“LEAP AHEAD” TECHNOLOGIES AND TRANSFORMATION INITIATIVES WITHIN THE DEFENSE SCIENCE AND TECHNOLOGY PROGRAM

TUESDAY, JUNE 5, 2001

U.S. SENATE,
SUBCOMMITTEE ON EMERGING THREATS AND CAPABILITIES,
COMMITTEE ON ARMED SERVICES,
Washington, DC.

The subcommittee met, pursuant to notice, at 2:30 p.m., in room SR–222, Russell Senate Office Building, Senator Pat Roberts (chairman of the subcommittee) presiding.

Committee members present: Senators Santorum, Roberts, Allard, Landrieu, and Bill Nelson.

Committee staff member present: Romie L. Brownlee, staff director.

Professional staff members present: Edward H. Edens IV, William C. Greenwalt, Carolyn M. Hanna, Ambrose R. Hock, Thomas L. MacKenzie, and Joseph T. Sixeas.

Minority staff members present: Peter K. Levine, minority counsel; Daniel J. Cox, Jr., professional staff member; Creighton Greene, professional staff member; and Mary Louise Wagner, professional staff member.

Staff assistants present: Jennifer L. Naccari and Suzanne K.L. Ross.

Committee members' assistants present: George M. Bernier III, assistant to Senator Santorum; Robert Alan McCurry, assistant to Senator Roberts; Charles Cogar, assistant to Senator Allard; Kristine Fauser, assistant to Senator Collins; Menda S. Fife, assistant to Senator Kennedy; Frederick M. Downey, assistant to Senator Lieberman; and William K. Sutey, assistant to Senator Bill Nelson.

OPENING STATEMENT OF SENATOR PAT ROBERTS, CHAIRMAN

Senator ROBERTS. By golly, on the last day of my chairmanship, we are going to start this thing on time. [Laughter.]

Welcome to this subcommittee hearing.

Ladies and gentleman, this afternoon the Subcommittee on Emerging Threats and Capabilities meets to receive testimony from representatives of the Department of Defense and nationally recognized researchers on the “leap ahead” technologies and transformation initiatives within the Defense Science and Technology Program.

The testimony that is provided today will help the subcommittee prepare its recommendation for the Fiscal Year 2002 National Defense Authorization Act. "Leap ahead" and revolutionary technologies have received a lot of press over these past years. The new administration has discussed investing in these "leap ahead" technologies and skipping a generation of weapons. These are intriguing propositions, to say the least, and we look forward to learning more details.

However, the subcommittee remains concerned that the base investment in science and technology must be strengthened, and revolutionary technologies must be refined and quickly be given to the warfighter.

Today we will hear from three panels on the efforts currently underway in the Department of Defense, in the services, Defense Advanced Research Project Agency (DARPA), our Nation's universities, and also, the small businesses to provide what we call innovative research into the most challenging problems facing our national defense.

I would like to welcome Pete Aldridge and Delores Etter.

Mr. Aldridge, I would like to extend my congratulations to you on your new position as Under Secretary of Defense for Acquisition, Technology, and Logistics. The subcommittee looks forward to working with you in this new capacity.

Dr. Etter, I want to especially thank you for your continuing hard work on behalf of our Nation's Defense Science and Technology Program.

I think all members of the subcommittee, all members of the full committee, all members who are even familiar or remotely familiar with Dr. Etter and her efforts wish to extend our sincere appreciation and recognition of her dedication and commitment as a true advocate for science and technology.

I know you are going to be moving on to new opportunities. The U.S. Naval Academy gains a great deal in this regard. I will not mention our loss in this regard, and with regard to institutional memory, expertise, and commitment, but they are considerable.

Please know your professionalism, energy, dedication, and expertise will be missed. I think you deserve an appreciative hand. Thank you very much for your service. [Applause.]

Now these two witnesses do not have a time limit on their testimony. However, when we get to the two other panels, they have time limits. It is my suggestion that your opening statements be held to 10 minutes or less.

I would be delighted to recognize the distinguished Senator from Florida for any statement that he might make at this time.

STATEMENT OF SENATOR BILL NELSON

Senator BILL NELSON. Mr. Chairman, it has been a pleasure to serve with you on this subcommittee on a subject that is most important to the future of this country; it is a privilege, also, to welcome to this subcommittee our old friend, Pete Aldridge, who years ago we were collaborating on scramjets and hypersonics, and all that. He brings to his new job in the Defense Department extraordinary experience and background. So I am delighted to be here. Dr. Etter, it is a pleasure.

Senator ROBERTS. Let me say at the outset that this has been a personal honor and privilege to be chairman of this subcommittee. This is not the last roundup.

We will proceed under the direction of Chairman Landrieu in the bipartisan fashion that we have achieved so far, but it has been a personal privilege.

This is a subcommittee that was originally suggested by Senators Coats and Lieberman, and followed up in fine fashion by the distinguished chairman of the full committee. It is a relatively new subcommittee, but I think we have done a great deal of good, especially in regards to science and technology.

I thank the Senator from Florida who brings considerable expertise in this area from the House of Representatives.

Mr. Aldridge, please proceed.

STATEMENT OF HON. EDWARD C. ALDRIDGE, JR., UNDER SECRETARY OF DEFENSE FOR ACQUISITION, TECHNOLOGY, AND LOGISTICS

Mr. ALDRIDGE. Yes, sir, Mr. Chairman. Thank you, and members of the subcommittee, for allowing me to come and join you today to speak on what I would say is a very important part of the defensive effort, and that's the Science and Technology Program.

As you have already mentioned, with me today is Dr. Delores Etter, the Deputy Director of Defense Research and Engineering, and overseer of the Science and Technology Program and budget. I share your views about the role and the contributions of Dr. Etter. I wish I could have talked her into staying. But she is on to bigger and better things, and we wish her well.

We have a joint statement that we prepared, that we will supply for the record. We will just summarize very briefly, and give you back some time for these very important topics and projects that have been occurring in the rest of the Department of Defense.

Senator ROBERTS. Without objection, it is so ordered. Please proceed.

Mr. ALDRIDGE. I have been on the job, as you mentioned, for 15 days and, therefore, my knowledge of the details of some of these programs is somewhat limited, although I hope to change that very rapidly.

However, I would like to summarize how our science and technology activities fit into the broader context of our acquisition efforts. Just after I entered this office, I established a new theme for how the acquisition function should operate. You have heard about acquisition reform, but I wanted to move to a new era.

Many studies have given us ideas on how to improve acquisition. We know we now need to implement these ideas. Therefore, the theme for the operation of my office will be "Acquisition Excellence," and science and technology will certainly fit into that "Acquisition Excellence" role.

I also established five goals for myself and the office about which I plan to run. Goal number one was to establish the credibility and the effectiveness of the acquisition and logistics support process. We need to focus on reducing cycle times, and to introduce program stability, introduce the evolutionary development, to reestablish our ability to convince Congress that we are operating these programs correctly. Credibility is one of those key elements that I plan to pursue.

Goal number two is to revitalize the quality and morale of the acquisition and logistics work force. We have seen significant reductions in the work force over the past several years, and we have basically told the work force that perhaps they are not as appreciated as they should be. I intend to focus my efforts on improving the quality and the morale of that work force.

Goal number three is to improve the health of the industrial base. We cannot have the finest weapons systems in the world unless they are produced by very healthy and productive and innovative corporations. So we want to be taking actions to improve the health so that there is an incentive to invest in our industry, there is an incentive for people to come into the industry, and that they can be as competitive, as strong and competitive as they can be.

Goal number four is to rationalize the weapons systems and infrastructure with a new defense strategy. Once the strategy has been completed by the Secretary of Defense, we plan to review the weapons system to see what weapon systems fit the strategy and maybe find and see some of those which do not. That includes the infrastructure necessary to support our force structures and end weapons.

Goal number five, and mostly related to the Science and Technology (S&T) Program, is to initiate those high leverage technologies that will give us the warfighting capabilities and strategies for the future. I agree with the notion of this subcommittee that we need to reinvest in our Science and Technology Program, and that will be one of my goals, to convince the Department and Congress that we need to do that.

As you can see, these efforts that we have in the S&T Program directly contribute to my fifth goal. As a result, the S&T Program will receive my attention and my commitment.

Mr. Chairman, that summarizes my statement. I would like to turn it over to Dr. Etter, please.

STATEMENT OF DR. DELORES M. ETTER, ACTING DIRECTOR, DEFENSE RESEARCH AND ENGINEERING; DEPUTY UNDER SECRETARY OF DEFENSE FOR SCIENCE AND TECHNOLOGY

Dr. ETTER. Mr. Chairman, I share Mr. Aldridge's appreciation for the opportunity to appear before you today.

My office has responsibility for the Department's Science and Technology Program. The Nation relies on the technological superiority of its Armed Forces. Our program's mission is to ensure that warfighters today and tomorrow have superior and affordable technology to support their missions, and to provide the revolutionary war winning capabilities.

I would like to make a few comments on five priorities of our S&T Program from a corporate perspective.

First, basic research is a long-term investment in our military's future. Previous investments have led to radio detection and ranging (RADAR), Stealth, night vision, and guidance for precision strike. We must ensure that we invest today in appropriate broad areas of research to be prepared for the future.

Second, strategic technology areas are priority areas we recently identified in a collaborative effort with the services and defense agencies to address emerging national security threats. These technology areas are divided into three categories.

The first is hard problems, areas where there are particularly difficult technical challenges. Examples include chem-bio defense modeling and standoff detection, and the defeat of hardened and deeply buried targets.

The second category is revolutionary warfighting concepts. These are the technologies that will lead to next generation capabilities, dramatically new ways of addressing military problems. This category includes network centric warfare, fuller dominance of space, and autonomous systems.

The final category is militarily significant research areas. These are technologies that will also be revolutionary, but still have a large component of basic research. Examples include nanoscience, directed energy, and advanced power.

A third priority is enabling capabilities, areas that have the potential to improve a broad range of existing and future system. Three such areas of significance to the Department of Defense are propulsion, software, and electronics.

Propulsion research includes high performance turbine engines, rocket propulsion, and hypersonics. In this work, we look at new capabilities as well as increasing fuel efficiency and noise mitigation in existing systems.

Software continues to grow in importance in our weapons systems as developments and upgrades increase reliance on software. However, problems attributed to software remain a significant contributor to the program cost, schedule, and performance shortfalls. To address these issues, we have established a Directorate for Software Intensive Systems within our S&T Program.

The Department cannot rely on the commercial market to fully address the electronics needs of the military, particularly in the areas of electro optics, infrared, mixed signal, radio frequency, and radiation hardening. Hence, it is important that we maintain robust programs in these areas.

A fourth priority is rapidly transitioning technology from S&T to an operational capability. The Advanced Concept Technology Demonstrations Program is one way to successfully take matured technology into the field in prototype systems. Recent successes include Predator and Global Hawk unmanned aerial vehicles.

Finally, a strong S&T workforce is a critical priority. The number of scientists and engineers we have is down 42 percent from the 1990 level. It is an aging force. The average age of the laboratory technologist is about 45 years, and over half of that workforce will be able to retire in the next 3 years. There have been numerous studies to look at these and related issues, and new efforts are now underway to address them.

In conclusion, the strength of the Department of Defense Science and Technology Program depends directly on the health of its partners. These include universities that provide new ideas and knowledge; service laboratories that provide stability and ties to the operational forces; DARPA with its commitment to high risk, high payoff programs; industry which provides innovation and transition of technology; other agencies that allow us to leverage their efforts; and our international allies which allow us to address interoperability from the beginning.

Mr. Chairman, I thank the subcommittee for this opportunity to share with you the corporate priorities of our Defense Science and Technology Program.

Thank you.

Senator ROBERTS. We thank both of you.

[The joint prepared statement of Mr. Aldridge and Dr. Etter follows:]

PREPARED STATEMENT BY HON. EDWARD C. ALDRIDGE AND DR. DELORES M. ETTER

Mr. Chairman and Members of the subcommittee, we appreciate the opportunity to appear before you today to discuss "leap ahead" technologies and transformation technologies.

TECHNOLOGICAL SUPERIORITY FOR NATIONAL SECURITY

The Nation relies on the technological superiority of its armed forces. As a result, the mission of the Defense Science and Technology (S&T) program is to ensure the warfighters today and tomorrow have superior and affordable technology to support their missions, and provide revolutionary war-winning capabilities. To do this we must understand the warfighters' needs. Fundamental to understanding those needs is an understanding of the strategic environment in which the warfighter operates, now and in the future.

The global spread of advanced technology is transforming the military threats faced by the United States. In order to carry out our defense strategy, the U.S. military must be prepared to conduct operations in any environment, including one in which an adversary uses asymmetric means such as nuclear, chemical, or biological weapons; information operations; ballistic missiles; and terrorism. Future adversaries will increasingly rely on unconventional strategies and tactics to offset the superiority of U.S. forces. Our combat forces must be organized, trained, equipped, and managed with multiple missions in mind. We must be conscious of these threats as we foster technology breakthroughs that will lead to new capabilities to cope with that environment.

Our vision for the 21st century is a warfighter who is fast, lean, mobile, and prepared for battle with total battlespace situation awareness and information assurance. Our Defense S&T program is focused on providing technologies enabling the weapons and equipment our combat forces will need to meet our strategic objectives in the future. The dawn of the information age has given rise to new revolutionary capabilities sparked by leap-ahead advances. For example, our Nation has led, and maintains a significant advantage in the development of information-based technologies. The Department has been actively pursuing improvements such as precision-guided munitions, the Global Positioning System, and satellite communications for decades. We are now only beginning to understand how significantly these information-based revolutionary capabilities will transform the essential elements of U.S. Forces. To succeed across the full spectrum of operations, the Department will develop innovative new concepts for conducting operations, test them through demonstrations, rigorous experimentation, and rapidly transition the enabling technologies into revolutionary war-winning capabilities.

The strength of the Defense S&T program depends directly on the health of its partners. These partners together provide the environment that supports the needs of the warfighter—from the universities that provide new ideas and knowledge; to Service laboratories that provide stability and ties to the operational forces; to DARPA for its commitment to high-risk, high-payoff programs; to other agencies that allow us to leverage our combined resources; to industry which provides innovation and transition of technology; and to our international allies for joint research programs that address interoperability from the beginning.

This statement summarizes the priorities of our S&T program from a corporate perspective. These priorities include:

- basic research, which provides the Department long-range research into areas likely to lead to advances in national security;
- technology transition programs that move S&T into the warfighter's hands;

• S&T which focuses the current and anticipated future high-leverage S&T efforts;
• enabling capabilities which benefit a broad-range of emerging weapons and human systems; and
• the health of the S&T workforce, which is one of our biggest non-technical challenges.

BASIC RESEARCH

New military capability and operational concepts emerge from many different sources. Historically, the Defense S&T program has responded to both the known needs for military capability and enabled the development of totally new operational concepts and capabilities. This has allowed us to keep the technological edge on which our forces have relied. It follows that the way to address future warfighting needs is to invest in broad areas of basic research that have high potential of yielding revolutionary advances as well as pursuing solutions to known operational problems. The basic research program provides support for research in the following twelve areas: physics, chemistry, mathematics, computer science, electronics, materials science, mechanics, terrestrial science, ocean science, atmospheric and space sciences, biological sciences, and cognitive and neural sciences.

Basic research is a long-term investment with emphasis on opportunities for military application far in the future and contributes to our national academic and scientific knowledge base by providing approximately 40 percent of the Federal support for all engineering research in universities. The Department sustains its investment in basic research because of proven, significant, long-term benefits to the military, which in turn enhances our national economic security. Basic research provided the foundation for technological superiority in each of our recent conflicts. Radar made a significant contribution to winning World War II. Stealth, lasers, infrared night vision, and electronics for precision strike played a major role in the Gulf War. Our Nation's defense advantage is founded on a wide scope of scientific and engineering knowledge. The Department must continue to invest broadly in defense-relevant scientific fields because it is not possible to predict precisely in which areas the next breakthroughs will occur.

TECHNOLOGY TRANSITION

Rapidly transitioning technology from S&T to an operational capability is crucial. Key mechanisms that have been established to improve the technology transition process include Joint Experiments, which are managed by Joint Forces Command, and Advanced Concept Technology Demonstrations (ACTDs), which are managed within the Office of the Secretary of Defense. These programs help to ensure the transition of innovative concepts and superior technology to the warfighter and acquisition customer faster and less expensively. The Joint Experiments program provides a venue to develop and experimentally test new concepts and technologies for the military. The ACTD program is used to determine the military utility of proven technologies, expedite technology transition, provide a sound basis for acquisition decisions, and to develop the concept of operations that will optimize effectiveness. Using this process, it has proven successful in taking matured technologies into the field in prototype systems. Recent successes included the Predator and Global Hawk unmanned aerial vehicles (UAVs).

Most ACTDs address warfighting needs addressed by the commanders in chief, hence they have strong representation in the process. The program also has strong ties with DARPA. Of the 84 ACTDs that have been initiated since the program's beginning in 1994, 33 of these were based on technology developed by DARPA. The ACTD program also works closely with the Joint Experiments program, which assists in improving and demonstrating ACTD products. To date, 37 of the ACTDs have produced 59 transitional products, 22 of which have proceeded to full-scale hardware acquisition. Transitional products include software developments that have already been deployed with warfighters. Ten ACTD transitional products, including hyperspectral scanners, unattended ground sensors and the Predator, were made available for Operation Allied Force in Kosovo. Using the aforementioned programs, we have greatly enhanced the mechanism to transition prototypes to the acquisition cycle.

KEY TECHNOLOGY AREAS

Over the past decade, the national security strategic environment has changed dramatically. This change in national security threats, and how we should respond to these changes is currently under review throughout the Department. The DUSD (S&T) and OSD recently led a collaborative effort, involving the key S&T leaders from the services, agencies, and OSD to closely examine the impact of the new security threats on what the Department needs from the S&T community. This process led to the identification of some areas we believe we must focus on in order to be effective in our mission in the future.

The needs have been divided into three categories: hard problems, revolutionary warfighting concepts, and militarily significant research areas. "Hard problems" are those areas where there are particularly significant technical challenges, which, if solved, would counter a significant operational or strategic threat. Examples include modeling the dispersion of chemical and biological warfare agents, and detecting and neutralizing hardened and deeply buried targets. Hard problems identify "technology needs" to overcome some particularly difficult security challenges we currently face.

Revolutionary warfighting concepts allow us to develop dramatically new ways of addressing military problems. These are the technologies that will lead to the next generation capabilities. Just like stealth, global positioning system, and night vision devices provided our forces a decisive advantage during Operation Desert Storm, these revolutionary warfighting concepts could lead to the novel capabilities for military forces in 2015.

Finally, are enabling technologies that will improve broad classes of weapon and human systems. Again, these capabilities can be revolutionary, but are broader based than revolutionary warfighting concepts, and include areas like advanced materials and advanced power.

Hard Problems

In recent years there has been an increasing proliferation of chemical and biological agents available to a wider number of adversaries. Technology developments are needed in chem-bio defense modeling and stand-off detection to provide an operational capability to remotely detect and identify potentially toxic chemical and biological agents and to forecast their dispersion through a defined battlespace. We need to focus on developing capabilities in four major areas: detection of biological and chemical agents and toxic industrial chemicals and materials; diffusion and dispersion modeling for predicting hazards; improved understanding of agent toxicity; and increased comprehension of genetic and chemical compositions.

Increasingly, potential adversaries are using buried facilities to protect their delivery systems, weapons of mass destruction, command and control systems and other military capabilities. This is an asymmetric measure to offset U.S. capabilities in intelligence collection and precision strike. Technology developments in time critical, standoff, and concealed target defeat are needed to provide an operational capability to safely identify and strike intended targets. Of specific interest is hardened and deeply buried targets, but the list also includes slowly moving targets (such as mobile missile launchers) and concealed targets (such as tanks hidden under trees). This area can be broken down into the following sub-areas where work needs to be focused: finding and characterizing targets through the use of novel sensing technologies, systems and munitions to defeat these "special" targets, and capabilities to assess damage to targets following strike.

The U.S. is faced with an increasing array of asymmetrical threats as potential adversaries learn of our capabilities and weaknesses. Preparing for and countering these asymmetric threats requires us to understand the mind of the adversary and then to dissuade threatening actions or to counter them. Technology developments are needed in counters to asymmetrical threats to provide an operational capability to respond to asymmetric threats by improved use of information operations, computational models and group-dynamics/social science theory to achieve "advantageous" shaping of the security environment. Focused areas where technology development is needed include: dynamic indicator databases, social modeling including group dynamics and decision support, and tools for information visualization.

With the proliferation of weapons of mass destruction and capable delivery systems worldwide, it is becoming increasingly important to defend against potential missile defense deep into an adversary's territory. Technology developments in cruise and ballistic missile defense are needed to provide the capability to remotely detect, track, and negate cruise and ballistic missile threats, providing a multi-layered defense and reporting capability. We need to work in the areas of: detecting and tracking strategic and tactical missiles through the use of enhanced sensing systems and novel signal processing techniques, advanced systems and warheads to negate enemy missiles, and providing affordable protection, including radiation hardening, for our defense assets.

As threats have evolved worldwide, we are fighting fewer large-scale battles in open areas and more small-scale conflicts in cities. Hence, we are in need of developing new techniques that are suitable for the complexities of urban areas. Technology developments in military operations in urban terrain are needed to provide a capability to locate, surveil, discern, engage, and neutralize threat forces within the close confines of an urban environment. We need to work on: enhanced situational understanding of the urban battlefield; improved training and mission rehearsal capabilities appropriate for the new environment; and faster, safer breaching technologies to allow our forces to move more effectively in urban terrain.

Revolutionary Warfighting Concepts

Technology developments in network centric warfare are needed to provide the operational capability to increase combat power by networking sensors, decision makers, and mission executors to achieve a shared awareness, increased speed of command, higher tempo of operations, greater lethality, and a degree of self-synchronization. The technology areas that require capability developments include: robust connectivity and interoperability of network systems; assurance that our information systems are secure against attack; operationally responsive and reliable networks; and tools for information understanding and decision support.

Space operations are becoming increasingly important to military operations. Technology developments aimed at fuller dominance of space are needed to provide technologies necessary to capitalize on the space mission and provide the United States dominant access to the military high ground that space provides. Nearly all other operational military concepts are aided by dominant access to space, which allows a decisive advantage in command and control of our own forces, coupled with enhanced reconnaissance of enemy position and intent. The technology areas include: affordable space transportation including advanced propulsion and long-lasting power systems; sensing technologies for enhanced space surveillance; space control, including on-orbit servicing; and protection of our assets in space.

Technology developments in unmanned systems for land, air, space, sea, and underwater are needed to provide systems that can execute an expanded range of missions in high-risk environments while keeping the warfighter safe. Autonomous systems range from sophisticated unmanned aerial vehicles—such as the Predator which deployed to Kosovo for reconnaissance missions—to miniaturized, inexpensive autonomous systems which can be deployed and operate together in a "swarm" to provide intelligence at "low risk." Capabilities that need to be developed for future unmanned systems can be divided into the following focus areas: enhanced unmanned system control; miniaturization of components; and integration and collective behavior of multiple autonomous systems.

Militarily Significant Research Areas

Speed-of-light directed-energy weapons—high energy lasers and high power microwaves—have the potential to perform a wide variety of military missions, including some that are impossible, or nearly so, for conventional weapons. These include interception of ballistic missiles in boost phase, defeat of high-speed, maneuvering anti-ship and anti-aircraft missiles, and the ultra-precision negation of targets in urban environments with no collateral damage. Technology developments are needed in directed energy to revolutionize military operations by exploiting the capabilities of directed energy weapons. Novel S&T to increase efficiency, decrease size and logistics, and improve maintainability of lasers and high powered microwave systems is needed.

A continuing challenge to military operations is to generate, store, use, and project electrical and other forms of power throughout the battlespace. Technology developments in advanced power are needed to improve the U.S. capability to focus power and energy, in a logistically supportable way. As these capabilities are developed, we will aid transformation of the force into a more maneuverable force that can precisely project power when and where needed. Our work in this area includes the Navy's development of technologies supporting an electric ship, and the Army's development of electric drive vehicles. Some areas where technology development is needed includes: energy storage and release, including novel battery systems and fuel cells; power generation and distribution; and new and refined applications of power technology.

The future military force will be involved in rapid and dispersed operations requiring individuals to work as a cohesive team, yet be capable of operating independently. The implications of this stressful, dynamic environment must be fully understood in order to improve decision-making processes, the training of decision-makers at all levels, and organizational patterns and procedures. Technology developments in the area of human dimension and psychological factors are needed to provide the capability to fully prepare all warfighters and support personnel cognitively and physically to conduct assigned missions and operations. The technology developments needed can be broken down into: training—including simulation based, virtual reality and augmented reality tools; decision making support, cognitive engineering to optimize human-information interfaces, and enhancement of performance under conditions of conflict.

Maneuver and self-protection are two enduring principles of military operations that remain true today. The Department remains committed to the development of smaller, lighter, and stronger materials and components that will enable enhanced maneuverability and self-protection by allowing these lighter and stronger systems. Technology developments in nanoscience and advanced materials are needed to provide revolutionary opportunities for the warfighter to develop totally new operational concepts and capabilities, based such developments. In a broad sense, the work in this area can be separated into two areas: nanotechnology, which enables very small mechanical systems; and advanced materials which are designed for specific applications, such as embedded computing, novel composities, and nonlinear, nonisotropic "smart" materials.

ENABLING CAPABILITIES

In addition to work in these areas, the Department continues to invest in longer term enabling capabilities that improve a myriad of systems. In each case, the enabling technology research leverages efforts going on in industry. We now describe three major long-term areas of focused R&D.

Propulsion

Military fuel consumption for aircraft, ships, ground vehicles and facilities makes the DOD the single largest consumer of petroleum in the U.S. Existing and emerging technologies are now available at various stages of maturity that could improve warfighting effectiveness through fuel efficiency. These technologies are applicable to the turbofan/turbojet, turboprop/turboshaft, and expendable engine applications, as well rocket propulsion programs. In addition, the rocket propulsion program addresses technologies to support space launch and orbit transfer propulsion (both liquid and solid), spacecraft propulsion (chemical, electrical, and solar), strategic systems sustainment (post-boost control systems, missile propulsion and life issues), and tactical propulsion (solids and hybrids). A working group has been established to formulate a National Hypersonics Technology Plan to spearhead a much more focused government/industry effort to develop hypersonic technologies, which could enable a whole new range of hypersonic air-breathing engines, weapons, and aircraft. All these propulsion programs are joint efforts with the Services, NASA, industry, and defense agencies.

Software

Software continues to grow in importance in our weapons systems as developments and upgrades increase reliance on software to provide the flexibility to meet existing and future unknown requirements. However, problems attributed to software remain a significant contributor to program cost, schedule and performance shortfalls. To address these problems we established a Directorate for Software Intensive Systems (SIS) that promotes and coordinates software related activities within DOD; we convened a Defense Science Board (DSB) Task Force on Software; and we chartered an SIS Steering Group of senior Service executives chaired by the DUSD(S&T) to articulate a Department software vision and guidance to the SIS Directorate.

The SIS Directorate established a coordinated approach to improving software acquisition in four areas: DOD acquisition policy, collaboration among DOD and Service software experts, education and training of the acquisition workforce, and science and technology transition. The initial actions of the Directorate are focused on responding to the DSB Task Force recommendations. The Directorate has absorbed the Software Program Manager's Network and is integrating its products and activities. We are implementing independent expert reviews throughout DOD to help Program Managers identify and manage software risk, and have completed 24 assessments. We are establishing guidelines for software acquisition management education and training of our workforce. We are sponsoring the Capability Maturity Model integration effort for enterprise wide process improvement. Finally, our Defense Software Collaborators provide a forum for communicating software issues and leveraging our scarce resources to address them. The SIS Directorate is a critical focal point for initiatives that reduce software acquisition risk.

Electronics

While the commercial market can be used to meet many of the electronics needs of the military, the Department has unique needs that are beyond the performance specifications needed for industrial applications. The Department has identified those areas where industry is not investing, but where advancement of technology is of key importance to the Department.

Four major thrust areas have been identified. Advances in electro optics and infrared technologies are expected to enable improved countermeasures capabilities, and counter-countermeasures capabilities such as the ability to detect camouflaged targets. Investment in mixed signal technologies would lead to enhanced performance and versatility through combinations of electronics, photonics, and micro electro mechanical systems (MEMS) technologies. Advances in radio frequency technologies (including vacuum electronics and wide band gap technologies) are expected to enable new communication, detection, and other applications with greater range and the ability to discern small targets. Finally, the goal of investment in radiation hardened technologies is to enhance protection of DOD's space systems.

WORKFORCE

A challenge facing the DOD today is that of enhancing and maintaining its S&T workforce. The intellectual capital behind DOD technology is the professional workforce in our 84 laboratories and research and development centers, which includes 28,500 Department scientists and engineers. This workforce is down 42 percent from 1990 end strength of 43,800. The workforce is also aging—the average age of the laboratory technologist is approximately 45 years and over half of the workforce will be able to retire in the next 3 years. The S&T workforce has been the subject of multiple Defense Science Board studies and independent analyses over the past decade with a common conclusion that this essential and aging workforce must be sustained and modernized—through creative recruitment and retention options—to provide future warfighting superiority within an aggressive commercial market for these skills.

We are working to implement new authorities recently enacted by Congress, including those that give laboratory directors many of the authorities that commercial lab directors have—such as the ability to hire on the spot when an outstanding candidate is identified and the ability to significantly reward employees who have made critical contributions to important programs, and the ability to offer competitive salaries. There are also efforts to look at providing opportunities for outside scientists and engineers to temporarily work in the DOD labs, and for DOD employees to spend time in industry.

CONCLUSION

Mr. Chairman, we wish to thank the subcommittee for this opportunity to share with you the priorities of our Defense Science and Technology Program.

In peace, technological superiority is a key element of deterrence. In crisis, it provides a wide spectrum of options to the national command authorities and commanders in chief (CINCs), while providing confidence to our allies. In war, it provides an edge that enhances combat effectiveness, reduces casualties, and minimizes equipment loss. Advancing affordable military technology and ensuring that it undergoes rapid transition to the warfighter are critical national security obligations.

Thank you very much.

Senator ROBERTS. Let me just start out here with a clarification in regards to the definition of "leap ahead" technology. As I have indicated, that has received a lot of press attention.

So, Secretary Aldridge and Dr. Etter, with that term, "leap ahead" technologies, define for the subcommittee what you think "leap ahead" technologies are.

Mr. ALDRIDGE. Let me start—it can be somewhat ambiguous. I try to use the term "war winning" technologies. People who would look at our stealth program in the 1970s and 1980s would perhaps define that as a "leap ahead" technology, something completely unusual, and would provide tremendous leverage of our military forces against any adversary.

It can be defined in that way. It could be defined as war winning. It could be defined as asymmetrical advantage, things which are unique that we have which provide us unique capabilities over an adversary. Any of those could be used to define "leap ahead" technologies.

Senator ROBERTS. Let us see. I'm writing this down. In the world of acronyms, we have the asymmetrical advantage technology. That is AAT. [Laughter.]

We have a war winning technology. I am not going to try that one. We have the "leap ahead" technology, which is LAT. We have got AAT, LAT, and WWT. [Laughter.]

You have to think in terms of acronyms, Pete.

Mr. ALDRIDGE. I did not—sir, I did not use a single acronym. I used whole words.

Senator ROBERTS. Bless your heart. [Laughter.]

We used to have a fish bowl in this subcommittee and for everybody that would use an acronym prior to saying the full name, or the agency, or the program, they had to put a dollar in. We could probably fund a great many things if we kept that up.

Now, Dr. Etter, in your view, what are we talking about when we say "leap ahead" technologies?

Dr. ETTER. I think of two categories when I think of "leap ahead" technologies. The first would be areas that do give us revolutionary new capabilities. An example of that, I think, is high energy lasers.

The second category that I think falls within that are designs of our systems that allow us to insert new technology that will give us dramatically new capabilities. So, this is looking at doing designs with the plan that we want to design them with; architectures that allow us to insert new technologies. That also will allow us to take very significant new increases and capabilities as we see new developments, particularly from commercial areas.

Senator ROBERTS. I think that is very helpful.

We have been joined by our next chairman, Senator Landrieu, who will be providing bipartisan leadership to this subcommittee.

We have just heard testimony from Secretary Aldridge and Dr. Etter. Dr. Etter almost received a standing ovation for her contribution.

We could do that, if you would like. [Laughter.]

So I would now like to turn to my distinguished ranking member, soon to be chairman, for any comments that she might like to make.

STATEMENT OF SENATOR MARY L. LANDRIEU

Senator LANDRIEU. Thank you. I would like to say, Mr. Chairman, what a wonderful job you have done in starting us off, and how much I have enjoyed working with you on this arrangement and how much I look forward to working with you, Senator, as we go through this change.

But although the chairs may change, our general philosophy that we have is really not going to change. I think we are very much in agreement about the things that need to be done, and to try to shed some more light on this particularly important subcommittee.

I want to thank you, Senator, for your leadership all of these years on the full committee as well as the subcommittee.

Let me just give this brief statement for the record, and then I have a few questions to follow up.

I want to acknowledge that the subject of this hearing, which is technology, is one of the most crucial aspects of our Emerging Threats and Capabilities Subcommittee. As we seek to transform our military and meet the challenges of the 21st century, we must continue to implement new technologies to keep our forces on the cutting edge, and ensure that they are prepared to deal with any threat that those who are hostile to us may be developing.

I also appreciate, Mr. Chairman, your commitment to the Department of Defense Science and Technology budget which is the foundation of this transformation which I think is going to be a challenge to us in this particular Congress.

Too often in the past, we have robbed this budget, cutting our investments in technology, to pay for current readiness. This approach may serve our needs today, but it will most certainly undermine our forces in the long run. That is going to be a great challenge of our subcommittee, to make sure that the budget supports the words and the directives and the suggestions that this particular committee will make.

We face a number of challenges in this area in light of tight budgets. It requires vision to invest in programs that may not have any immediate payoff, but in years to come will have substantial payoff.

Second, we must ensure that the Department of Defense can keep up with the ever quickening pace of technological development in the commercial world.

Third, we must be competitive with the private sector in attracting our Nation's best and brightest young scientists and engineers. These issues are of vital importance to this subcommittee I look forward to continuing some of the work that has been laid out, and even adding to it, as I assume the chairmanship, and look forward to working with all of you. I reserve my questions until the appropriate time.

Thank you for appearing here today.

Senator ROBERTS. We thank you for your statement.

Secretary Aldridge, as we know, the Department is undergoing a strategic review. The Secretary was here just last week giving members of the full committee an update. One of the studies with regard to this review is the future of defense research and development, and in particular science and technology.

Let me ask the first obvious question. Have you been consulted to date on the strategic review as it relates to changes in the research and development accounts?

Mr. ALDRIDGE. Yes, sir. I have been involved in the decisionmaking process that the Secretary has. He has incorporated into this process many members of the Department of Defense, the Service Chiefs, the Commanders in Chiefs of the various theater forces, theater commands. He has been involved with getting their views on various topics. Science and technology, and research and development is one of those.

Senator ROBERTS. As I understand it, one of the defense strategy new objectives is to provide recommendations for allocation of acquisition and R&D resources. So could you comment on what your recommendation for the R&D resources would be?

Mr. ALDRIDGE. I have made a series of recommendations and suggestions to the Secretary. He is considering them. He has not made any decisions regarding how he wants to proceed.

I have discussed it with him, the necessity of increasing research and development, and specifically the science and technology budget, to bring the budget back up to a level that supports our future capabilities against a very unknown and volatile world in the future.

I have made that recommendation. He has not shared with me his decision on how to proceed on that. I cannot say exactly how he plans to formulate the final decision in getting ready for the fiscal year 2002 budget amendment that is in preparation.

Senator ROBERTS. I have one other related question, and then I want to recognize Senator Allard if he has an opening statement. Then I am going to yield to my colleagues, but then I am going to come back with additional questions.

There are several aspects of the R&D enterprise that are what I would call new approaches. I understand that last week we had been briefed about that in regards to the Defense Strategy Review. I am talking about staff. These new approaches have been discussed and in review process.

Let me just mention a few that you might want to comment on: Moving from the chronically under-investment in R&D to a sustained, healthy level of R&D with a percentage of it earmarked in the Department of Defense and the service budgets for something called "Over the Horizon Research"; second, moving from a zero defect mentality to an acceptance of risk and failure in programs, obviously necessary for a successful overall R&D effort; third, moving away from an inflexible acquisition process to a spiral acquisition process, allowing various program development paths.

I am particularly interested in any explanation you might want to give the subcommittee about the spiral acquisition process and the philosophy behind what we call spiral technology insertion. If you would like to comment on any of the three, especially the last, I would like to hear it.

Mr. ALDRIDGE. I am not sure if I can define that term either, sir. Let me talk about spiral development. That is clearly one of the items of interest for the Department. In fact, we are in preparation for a new DOD regulation that calls for the spiral or evolutionary development of systems. It has some very favorable advantages in the sense that you can get weapons into the fields sooner. You can reduce the risk, you can reduce the uncertainty of costs, and you can get rid of older weapon systems which tend to operate at a higher cost than the newer ones.

Spiral development is a positive direction that we need to go to get our cycle times down, and to get the systems into the field as quickly as possible. We support that. It is something we ought to be doing.

We have to recognize that the first system in the field is not going to be the ultimate system. We have to have it adaptive to changes in technology with time, and improvements with time that will eventually get to the ultimate configuration.

One might describe the difference between an F–22 which is a system which has gone to the ultimate capability off the bat, versus the Joint Strike Fighter, which is, in fact, an evolutionary program. Global Hawk is another example of an evolutionary type of a program. That is one piece.

The other comments that you made about “Over the Horizon Capabilities,” and the introduction of that was a suggestion that we have some fixed level of—I would call science and technology should be fixed. The research and development which carries forth other types of more or closer to weapon systems development, probably it would be variable with time.

But the science and technology being something that should be set at some percentage of the defense budget, and held to that, I would certainly support. It is something we need to do. It has tended to be in the past a bill payer, and I think that is the wrong attitude for the science and technology budget to be pursued.

Senator ROBERTS. This subcommittee certainly shares that view in spades.

Dr. Etter, do you have any commentary on that from the standpoint of your experience?

Dr. ETTER. Yes, I would like to add two things. One, you mentioned the problems when we have a zero defect mentality as we think about science and technology. I would add that it really is important that we move away from that because particularly when we are working with new concepts and new innovations, we learn as much from our mistakes as we do from things that work right.

We need to have an environment where people are comfortable with trying new things without having to feel that they have to work in order for the project to move ahead.

The other thing I would add has to do with the spiral development. I would add there that this is particularly important in the software arena. When you look at our systems with software codes of many million lines of codes to do all of the capabilities we would like to get, one of the ways we are going to be able to get our hands on the kinds of problems that we are experiencing here is to try to deal with smaller systems that have only part of the capabilities, and then continue to upgrade.

So, I think spiral development will help us all around, not only just in the hardware developments, but also in the software developments that supports that.

Mr. ALDRIDGE. There is another piece of it, just to add. It is stability to a program. When you do the evolutionary spiral development, you tend to have a better understanding of what the program is capable of doing. You are not taking as much risk as you would if you went to the ultimate configuration.

Therefore, when you come over and explain what a program is going to cost, its schedule, and performance, we are closer to being correct as opposed to having a program that has a little more risk, and we have a tendency to be wrong, and have to ask for more money, and have to ask for slippages in the program.

I think as we go through the evolutionary process, our credibility and being able to explain what a program is going to do, what it is going to cost, when it is going to be, what schedule it is going to be on, we have a much better ability to do that than we would have otherwise.

Senator ROBERTS. Let me just say that, your point in regards to shortening the time for delivery of the warfighter, that really strikes home with me. I am aware of our services in test with DARPA and other folks.

I know that DARPA's main function—and I am paraphrasing here—is on the crest of the wave. So many times, our service members indicate, "Hey, it is not the crest so much; I need more of the wave, and I need it now."

It does not have to be, so many times it is, "Well, that is not scientific enough."

I hate to use the word "sexy," but that—well, I will not. Strike that. [Laughter.]

Is that all right? If you say it is all right, it is all right. [Laughter.]

That reminds me of the Ed Sullivan Show. [Laughter.]

Let me say that in terms of the helmet that I had hoped would be available to the Marine Corps 4 years ago—now I have to admit I am old corps, and the current helmet, you cannot sit on it. You cannot cook in it. You cannot shave in it, and it weighs too much, and it certainly hinders your view, and it looks like a German helmet to begin with. [Laughter.]

Senator LANDRIEU. But other than that, he likes it. [Laughter.]

Senator ROBERTS. Yes, but other than that, I like it a lot. [Laughter.]

But it is just that I cannot understand why we cannot get that kind of equipment that we really need faster. You are saying that this new kind of process might be able to be of help, is that correct?

Mr. ALDRIDGE. Yes, sir.

Senator ROBERTS. OK. I appreciate that.

Senator Allard, do you have an opening statement, sir? We can follow the regular order for questions. We thank you for coming.

STATEMENT OF SENATOR WAYNE ALLARD

Senator ALLARD. Thank you, Mr. Chairman. I just would make just some brief comments. I appreciate your holding this hearing. I think it is important, and perhaps even just a little bit theoretical, with the fact that we do not even have our defense budget numbers right now to deal with it.

But I think it is important that we maintain our emphasis on research and development. We have technologies out there that are reaching out a long ways. Certainly this is one member who does not expect them to work all the time. We have to continue to push the envelope.

I know you are committed to that effort, and I know that the witnesses that we have here today are committed to that effort. I just look forward to hearing what has to be said here, and that is all I have, Mr. President—Mr. Chairman, soon to be ranking member. [Laughter.]

Senator ROBERTS. Yes. If I cannot be chairman, there is always president. [Laughter.]

I did not say president of what. [Laughter.]

If I might ask one other question and then move on to Senator Landrieu, Senator Nelson, and Senator Allard.

I am going to ask you the "bigger than a bread box" question. What percent of the defense budget should be the S&T account, or what should that amount to? I know you are not going to answer that. You can if you would like.

Now, Dr. Etter, you can say anything you want to now. [Laughter.]

Is there a range? Is there some kind of a range here? Because as you have indicated, Secretary Aldridge, this has been a bill payer account. That is most unfortunate. It is something we want to change. Do you have any comments?

Mr. ALDRIDGE. Sir, again, it is a part of the process that we are going through. I do not mind saying this: It should be somewhere in the range of 2½ to 3 percent of our budget. It has not been that in the past several years.

Some time in the past, it was at that type of level, but in that range is something that we need to focus on. I think it ought to be constant. We ought to be planning that this is what is going to be as a percentage of the DOD budget. If Congress agrees that the budget should go up, then the percentage and the amount of money going into the S&T program should go up accordingly.

Senator ROBERTS. Bless your heart. I am so happy to hear you say that. It mirrors what Senator Landrieu said in her opening statement, and I applaud that statement.

Senator Landrieu.

Senator LANDRIEU. Let me just follow up on that point and that figure. The record was 2½ to 3 percent. But try and help think for a minute of a large company that does comparable work.

What do you think the comparison would be to the private sector for their R&D piece, if that would be a fair question? I guess my question would really be: How did you arrive at your 2½ to 3 percent? Walk us through that.

Mr. ALDRIDGE. That is an excellent question, and it is very difficult to compare an industry and what they would be spending in research and development. You would find in some industries it is around 5 percent. In some of the software industries, it could be 10 to 15 percent.

But in comparing it to the Department of Defense, it is different because there is a science and technology budget which is not that directly related to weapons systems. Then there is a research and development activity that is, in fact, related to developing a weapons system of a particular kind.

The contractors are paid for that type of research. So it is not counted in their independent research and development (IR&D) program, so to speak. So it is hard to measure how much that ought to be.

If you look at the past history of what we have been able to do with our Research and Development and S&T Program, one could say that that range of number makes you comfortable that we can do the things we need to do to stay ahead with that type of a level of effort.

If you got below that, something has to give, and it is usually the basic research that goes. The "leap ahead" technologies go. People are not as willing to take as much risk with the money they have left and so, therefore, they are not pushing the state-of-the-art.

When the numbers are in that range, we believe we have enough resources to really push out and do the innovation that is necessary and take a little more risk than we would have otherwise.

Dr. ETTER. Could I add something to that? A recent Defense Science Board study looked at this issue because it is a very difficult one. They looked across many different industries at the percent that they spent on science and technology or research and development.

One of the things they found that relates here was that, first of all, in industry, often their research is fairly short-term research, 3 to 5 years, where a large part of our research really has to be much longer-term, 10, 15, or 20 years.

If you look at companies that have a longer-term research, you are looking at companies like pharmaceutical companies which do have to have this very long reach. They tended to spend around 3 percent on their research activity. So, I think that gives one a sense that Mr. Aldridge's percentages are in the right kind of ballpark for a company that is looking further out.

I would like to add one other thing on percentages. When you come up with a percent—and I do think this is actually a very good way to think about what kind of investment we should have in S&T—you can look at the overall number, the 3 percent for the overall budget. But it is extremely important that you go down to the individual services, also, because that also is a very critical part.

We really should be looking at services getting to something like close to 3 percent of their budget. There is quite a range today among the services, and I think that you do not get the right picture unless you look at what percent is being spent of each service in their overall obligation authority.

Senator LANDRIEU. I appreciate that because I hope that the members of our subcommittee can really embrace this goal and help our full committee, and Congress, to stay disciplined in order to do this because there are always things right now, tomorrow, next week, that need to get funded. This is a constant debate that goes on.

But I hope that our subcommittee will really rally and advocate and work in a bipartisan way to really press ahead because it just makes such common sense. Being able to explain this to our constituents and to measure it in ways that the public can understand gives us that political attitude, if you will, to press our case.

Let me ask another question about some of the problems. This immature technologies problem, we have been often criticized—and I think in some ways it is justifiable—that private industry can field a product so much more quickly and faster in terms of cycles than we can. They make sure that their technologies are proven in a laboratory before they try to incorporate them into new products.

Do you agree that our immature technologies are, in fact, a problem? If not, why not? If so, what steps are being taken that we should be aware of that can help make sure those technologies really work, and get that quickly decided and then move them into the field? Either one of you can start off.

Mr. ALDRIDGE. Let me start off in a broader sense of the problem of getting our technology in the field faster. It is unfortunate that we are in the process of a budget that when we have an idea, that we want to do something, it takes 2 to 3 years to get that program funded because of the budget process.

I do not have an answer to this, but there could be some kind of a line item that where we find the technology, we have a budget already established to go fund it immediately. I do not know exactly how to do that, but the budget problem that I am aware of does create this lag in time of idea to actually getting started.

Dr. ETTER. I would agree with that, and then go a little bit further on the maturity levels. One of the things that is in our new 5,000 series which describes the new acquisition process is a requirement to do technology readiness levels. This is a requirement that is now put upon the science and technology community to give essentially a number rating to technology as it is ready to move into acquisition.

I think this is going to be extremely helpful. It allows us to communicate between the science and technology community and the acquisition community.

What I hope it does not become is a way to say, "technology should not move into acquisition unless it reaches a certain level."

What we really should use this for is to make sure that the program managers understand the risk that they are accepting so that it really allows the communication to say if this is an extremely important technology for you to put into your system, by giving it a technology readiness level that indicates that it is not as mature as you would normally like, the program manager then knows that he is going to have to put, for example, more dollars into risk reduction efforts and things like that. So it helps you to avoid surprises.

That is one of the most important things you want to do, is not to have surprises in the maturity of the different technologies that are going into our systems.

Senator LANDRIEU. Thank you.

Mr. Chairman, I have other questions, but there are other members so I will reserve to ask them later.

Senator ROBERTS. We can come back if we have time.

Let me recognize the distinguished Senator from Pennsylvania, Senator Santorum, for opening comments he would like to make.

STATEMENT OF SENATOR RICK SANTORUM

Senator SANTORUM. Thank you, Mr. Chairman. I have an opening statement that I would like to put in the record. I just want to make a few comments.

Senator ROBERTS. Without objection.

Senator SANTORUM. First, let me just thank you for holding this hearing. This is a hearing that I requested. You supported an amendment that I offered to the budget resolution which dramatically increased the amount of funding for S&T research.

Senator Lieberman and I did work on the subcommittee having to do with air/land procurement. We have had many discussions about our concern for looking at our procurement tail that we have, and the huge amount of commitments that we are about to make for the long-term, on major acquisition projects, as well as others that are in the offer, and looking at that commitment that we have to make and the impact of that in the out-years for our budget.

We are just wanting—and certainly we are thinking out loud, what is happening here in the next 5 to 10 years that may make these decisions either good decisions or bad decisions? Should we be at least integrating or at least be knowledgeable about what is on the horizon to either effect the decision that we make or make sure that we are capable of integrating that into the platforms that we decide to make, or basically fundamentally either scrap it or go to a different platform?

That is the reason that I asked for this subcommittee to do this. I have some concerns that go beyond that, obviously, with particularly the research that is based in our academic centers, and the impact that we are having, not just on the amount of research being done there, but the training of engineers and scientists.

I have been very supportive and am a very strong supporter of putting more money into NIH. I am all for putting more money in health research. But we are consistently lowering the amount of money in real terms that we are spending on S&T in our budgets in the military.

The impact of that on our scientific community and our basic science research is profound, in our ability to have trained scientists and engineers who are going to be developing that next generation of warfighting capability. So I do think it is important for us to renew that commitment now that we are looking at a new vision for the military, that we re-energize and redouble our efforts to put more resources in the area of basic research and in our university communities, not just for the research value, but for the education and training component that comes with that.

With that, Mr. Chairman, I apologize for taking so much time, but I appreciate it.

Senator ROBERTS. The godfather of the hearing is entitled to take whatever time that he might wish. [Laughter.]

[The prepared statement of Senator Santorum follows:]

PREPARED STATEMENT BY SENATOR RICK SANTORUM

Chairman Roberts, thank you for convening this important hearing today. In l999, then-Governor George W. Bush addressed an audience at The Citadel in South Carolina and raised the notion of skipping a generation of weapons systems and of making "leap ahead" advances in American military capabilities. Governor Bush recognized that 21st century threats facing the United States are qualitatively different than the threats that occupied our military and our industrial base during the Cold War and the decade that followed the downfall of the Soviet Union.

Since that speech, many others have articulated a need to transform our Nation's military to better respond to these threat trends. They note that our current military is ill-equipped to meet threats such as incidents of terrorism, information warfare, biological warfare, and urban conflict. The only way to meet these challenges is to redouble our energies on meeting these challenges. While procuring updated or evolutionary weapons systems might seem like the most expeditious way to meet these new threats, I believe that we need to work our way back and look first at the basic sciences and basic research efforts that will support the development of new weapons systems.

For advances to occur in these capabilities, we will first need to make wise investments in key enabling technologies. I believe that Department of Defense basic research can provide the stimulus to make this possible. For this reason, during the Senate's consideration of the fiscal year 2002 budget resolution, I offered an amendment that provided an additional $353.5 million in Department of Defense basic research funding spent in American universities.

Earlier this year, Senator Lieberman and I discussed potential hearing topics for the subcommittee on Airland. During our discussion, we shared our concern that Congress may not have a full or accurate picture of many of the ongoing advances that are happening in the areas of warfighting technologies. Senator Lieberman and I concurred in thinking that this imperfect or inaccurate information may lead Congress to make serious investment errors with respect to our limited military resources. Our greatest fear is that Congress will authorize and appropriate funds for programs and/or technologies with little or no applicability to 21st century threats.

With this background in mind, I contacted you with the hope that you would conduct a hearing focusing on current advances in warfighting technologies taking place within our Nation's science and technology programs—in academia, Federal Government, and within industry. I encouraged you to invite witnesses from these three communities so that they might address and illustrate many of the technological breakthroughs that are occurring in our science and technology programs. I am glad to see that representatives from these three communities will be appearing today before this subcommittee.

I would also like to thank you for honoring my request to include two witnesses who have first-hand knowledge in two "over-the-horizon" technologies—nanotechnology and micro-electromechanical systems (MEMS). I believe that members of the subcommittee will benefit from the testimony of Dr. Cynthia A. Kuper, President, Versilant Nanotechnologies, and Dr. Kaigham J. Gabriel, Professor, Electrical and Computer Engineering, Carnegie Mellon University, and their insights on these two important technologies.

It is important to focus on "over-the-horizon" or "leap ahead" technologies because of the revolutionary powers of change these technologies can produce. As author Raymond Kurzweil notes, "our forebearers expected the future to be pretty much like their present, which had been pretty much like their past . . . [yet] few have truly internalized the implications of the fact that the rate of change itself is accelerating." The author argues that technological change is exponential and that "most technology forecasters ignore altogether this historical exponential view of technological progress. That is why people tend to overestimate what can be achieved in the short-term but underestimate what can be achieved in the long-term." It is for this very reason that the subcommittee should pay particular attention to these "leap ahead" technologies.

Again, thank you for your willingness to schedule such an important hearing and I look forward to the testimony of our witnesses.

Senator ROBERTS. Let me refer then to Senator Lieberman as the goduncle, I believe.

Senator SANTORUM. Not the godmother, I know.

Senator ROBERTS. No, no. [Laughter.]

We may have to have a bipartisan amendment along with Senator Santorum, too, on the funding level if we maintain the S&T budget to the degree that we remain competitive.

If we do not maintain our technological advantage in our military capability, our national security capability, I can assure you that the red carpets that are usually out in Europe for all of us who go there from time to time will turn to standard gray, or maybe French—or whatever.

Senator LANDRIEU. Do not give the French anything to be—[Laughter.]

Senator ROBERTS. Well, that is another whole story. [Laughter.]

But at any rate, also the respect of our adversaries. I cannot tell you how important this is from a national security standpoint.

Senator Nelson.

Senator BILL NELSON. Thank you, Mr. Chairman.

Some of our most productive "leap ahead" technologies have often been associated with space. So I am curious, Pete, how does DOD's S&T strategy fit in with the national space strategy?

Mr. ALDRIDGE. As you well know, I am delighted to answer that question based on my space background. There are several things that we are doing in the space arena in relating—in fact, I was thinking as you challenged me in "What were "leap ahead" technologies," Mr. Chairman, I started to think about some of them.

Some of them were, in fact, from space, the real time capability of our reconnaissance capability. Space shuttle, I would said was a "leap ahead," and space-related things like SR–71. The airborne laser is clearly a "leap ahead" technology, and even the UAVs are in some cases "leap ahead" technology.

I guess you know it when you see one is the best I can describe it. It is hard to put a definition of what one is until you actually see it.

Space phase radar is one, Senator Nelson, that we are working on very hard that is in the S&T program both from the standpoint of putting an AWACS in space that would detect the airborne targets to putting JSTARs in space that would detect moving targets on the ground. There are some significant technologies moving in that direction.

Certainly, the reusable launch vehicle technologies, while that has been a NASA directed program, the Department of Defense is very interested in looking over the shoulder to make sure that when that comes to the point of fruition, the Department of Defense can use that technology when it is available.

We are also looking at new things in the space surveillance, being able to understand the situation awareness in space. We are looking at technologies to protect our own satellites from hostile action in space. We are looking at technologies that would deny the adversary the use of space when it is detrimental to our interests.

It is just a whole range of capabilities that we are looking at that would give us the continued asymmetric advantage. I will use that term again. There is no country in the world that can match us in our capabilities in space, and no one will for a very long time.

However, there are things that people can do with the new technologies that exist in space by acquiring them from the commercial sector, and can use them detrimental to our interests. We want to be able to make sure our systems operate as they are planned; and in cases where an adversary is using space detrimental to our interest, we can deny him that capability. All those things, I believe, we need to work on. All of those are covered in our S&T program.

Senator ROBERTS. Senator Allard.

Senator ALLARD. We have a lot of technology that is moving forward in the private sector as well as in the Defense Department. In some cases, one wonders if we are able to stay ahead of the private sector with some of the research. Would you comment about some of the competition you feel from the private sector?

Mr. ALDRIDGE. Let me start, and I will have Dr. Etter continue. Yes, sir, we have a problem in our ability to use the technology from the private sector because we make our rules and regulations so burdensome for the commercial companies to do business with the Department of Defense. I think we have to address that problem first so that we have companies like Hewlett Packard who have tremendous technologies that can bring to bear to the Department of Defense, that it is commercially attractive for them to do business with us.

That is one area that we can then get access to that capability which has, like you said, turned around very quickly.

But the other side is that in many cases where there are unique military requirements, that in some cases, we are, in fact, ahead of the commercial sector. In some of these cases we just talked about, space phase radar, for example, there is at this point no really unique commercial requirement for such a thing. In some of the very high data rate capabilities that we have need for in the military, the commercial sector has not yet caught up with us.

But there are many other things which the commercial sector is providing with respect to information technology that we should be taking advantage of because—but we do not make it friendly for them to do so, we need to go work on that.

Dr. ETTER. I would add from another perspective, one of the real challenges we have is just knowing what is available in commercial industry. That is a growing challenge because it is something that we need to be aware of, not only with what is going on in our country, but really what is going on globally.

There are a number of efforts that try to look at that. Each of the services has their own efforts to look at technology. We have some international technology watch programs where not only do we participate, but some of our closest allies work with us to try to help us all stay aware of what is going on in technology.

But I think that is going to continue to be a growing challenge, to know what is going on. But it is very important, and I think it is a real responsibility of the Department because we want to be sure that the dollars we spend on science and technology are not dollars doing something that commercial industry is doing; or if there are some very common interests, perhaps leveraging. But I think it is something it is a responsibility, but is going to be a growing difficulty to really stay on top of.

Senator SANTORUM. Would you comment a little bit further on the cryptological challenges that you have?

Mr. ALDRIDGE. I am not sure I can, like I said, I have been on the job for only 15 days. I have not gotten into that part as of yet. I know we do have some challenges and, of course, working with the National Security Agency to work those things out. But I am afraid I cannot answer at this point.

Dr. ETTER. If I could add from one perspective, we have worked closely with NSA on some issues that relate to supporting their cryptography needs. These have fallen in the areas of high performance computing because there are certain kinds of capabilities from high performance computers that they really require for some of their needs. We have worked closely with them.

This has involved looking at some additional support for commercial companies doing this, but also putting in place some initiatives for research to try to help do the kinds of initial research to help our companies within the U.S. be more competitive in some of these very high end areas and architectures.

Senator ALLARD. Thank you.

Senator ROBERTS. Senator Santorum.

Senator SANTORUM. Thank you, Mr. Chairman.

Just a couple of comments: First off, if we were successful in doubling your basic research budget, what would you do with the money?

Mr. ALDRIDGE. Double it? [Laughter.]

Well, let us see. I have a few areas that I think are important for us to delve into. They are consistent with the strategies that are laid out in our formal statement for the record.

But I think information technology comes to the top of my list of things that we ought to be working on, both information assurance that we can operate in ways that an adversary cannot disrupt; our growing dependence upon information for our capabilities; as well as our information warfare. We need to be able to deny the use of that capability to an adversary.

But information technology, to me, would be high on my list because in a conflict, the ability to deny information I think is something that adds more to deterrence that anything we can do. So that would be high on my list.

The second would be space systems. Space is a very important part of our capabilities to conduct military operations. There is nothing we can do in the military in terms of targeting that space is not an essential part of understanding where the targets are, the communication systems, the navigation systems, the bomb damage assessment, the weather predicting. Everything we do is essential to space, and we need to continue to develop our dominance in that particular area.

Directed energy is an important future war winning capability. Unmanned systems are important, both unmanned reconnaissance and unmanned combat vehicles. Nano and micro technologies are something that we could continue to spend money on. Ballistic and cruise missile defense are very important issues for the future. These are the areas that I would focus on with the additional resources.

Senator SANTORUM. I would like to talk a little bit about nano and MEMS, if you will. My understanding is that your nanotechnology initiative is called the Defense University Research Initiative on Nanotechnology. Can you explain that and what is going on in that program?

Dr. ETTER. Yes. This is a program that we work on with a number of other agencies. I think the area of nanoscience and nanotechnology is one that people recognize is a very critical one.

Over the last few years, there have been interagency groups that have worked together to look at this area and to also divide up areas of emphasis so that we can get the most out of the dollars that we are putting into this.

For example, NSF is one of the key players in it. DOD is also a key player, and the program that you described is the one that we have used to try to focus our efforts in this area. But it is looking at nanoscience and nanotechnology, particularly with a look at applications that we think will be important to DOD.

For example, one of these is new energetics, new materials. We are also very interested in things that may allow us to come up with new power sources that would allow us to have smaller, lighter weight systems. We think nanoscience is going to be another part of that.

But this program is one that is focused entirely on universities, and it is built around a multi-disciplinary university research initiative. So it is encouraging collaborative efforts among universities.

We think this is a very important program, and have planned in that to make sure that we have a continuing support, not only for the programs that are currently being funded, but for bringing in new programs each year.

Senator SANTORUM. When you are doing that kind of research whether it is that or others, how does that research that is going on intersect with the development of weapons systems that are ongoing at the various stages of procurement?

Mr. ALDRIDGE. Yes, sir. Let me address that. It so happened in my previous job—I was a CEO of a corporation in California that launched the smallest satellites ever put into orbit. They are called Pico Sats. They are one pound satellites that are a little larger than a cigarette package.

But we were looking for technologies that—what could demonstrate technologies that then the program managers who have weapons systems to deploy feel confident that can take the technology, we can show that it works, and that they would be more comfortable then to apply it to their program. They are very prone—not prone to risk, until they have demonstrative capabilities.

There are several activities underway to develop micro technology for weapons systems such as artillery shells. There is some work going on at Draper. We have had some work going on with NASA to put nano MEMS technologies on shuttle flights, for demonstration of technologies; looking at technologies that also would be applied to very small satellites like Pico Sats; looking at communication systems, reconnaissance systems, and things of that nature.

What is from the university and the laboratory, we have to take a step to demonstrate that those capabilities are valid so that the program managers who have a need for these smaller, more capable systems will apply it. I think there is a history or trail that has to be provided there.

Senator SANTORUM. Do we have existing a pretty good funding of that trail? I mean, is it—do we have enough resources—first off, I guess the basic question is: Are we doing enough basic research? I think, at least from my perspective, I do not think we are, but I would like your answer.

The second is, once that basic research is—how are we bringing that through to where it becomes relevant to the guy who is the program manager who is looking at the project?

Mr. ALDRIDGE. In the past, we probably have not done or funded sufficiently. We could do a better job. If we can get our S&T budget up to some of the percentages that were discussed earlier, 2½ to 3 percent, more funding would be available to have application for that type of technology that may accelerate it for use in the future.

Dr. ETTER. If I could add to that a little bit: When we have our basic research programs like the nanoscience one that you just mentioned, the dollars come out of an OSD account, but when the programs actually get funded, it is done through a service. So the services really do the execution.

One of the things that this provides is a very close tie to one of the services and the research that is being done. That is often where the first steps are made in terms of working closely with the researchers to see what is coming out, and then try to identify that into applications that then are applications that tie into operational systems.

Mr. ALDRIDGE. Senator, one point, I was aware of some work going on at Draper Laboratories in this area, and one of the strongest motivations for the MEMS technology is commercial application.

The commercial people who will be looking at these kinds of devices to put in automobiles, and millions and millions of devices were the ones that were the most interested, and were driving the research program to the point of accelerating the MEMS technology for commercial. It so happened that the military was riding on that commercial bandwagon, so to speak.

Senator SANTORUM. My final question, I know my time is up, but if you would indulge me in one thing.

My opening comments, to tie into those, are there things going on out there in the basic research world that you see that fundamentally affects the decisions that Congress has to make in the next year or 2 with respect to weapons platform or other types of acquisitions that we are going to make that should cause us to rethink about the commitment to those kinds of platforms?

Mr. ALDRIDGE. The answer to that is yes. If you look at the trend of the basic research budget over the last 5 or 6 years, that trend has been downward. That is not a healthy sign. It should be reversed.

Senator SANTORUM. I do not think you understood my question.

Mr. ALDRIDGE. OK. I am sorry.

Senator SANTORUM. We are making commitments to a variety of different platforms that we are going to eventually deploy, acquisition programs. Are there things going on within the research community that, in looking at the prospects for this research, in light of the decisions that we are going to make on acquisitions, that would cause you to say, "Hey, wait a minute. Maybe there are things coming down the line that would make this investment at this time and this commitment"—because you know these things have long tails—"an unwise decision"?

Does that kind of analysis go on within the Department, or are we so stovepiped that that kind of interaction really does not occur to the degree that is necessary in this incredibly fast-paced evolution of technology that is going on in our society?

Mr. ALDRIDGE. I—that is a——

Senator SANTORUM. I thought I would give you an easy question to answer. [Laughter.]

Mr. ALDRIDGE. Very tough question to answer. I would hope that that type of analysis does exist. I believe it does.

I know there are—I have seen personally in the short history that I have been on this job, and certainly in the past history, where people are looking at technology working that says, "Well, this technology is going to make this either obsolete"—if this is what you are getting to—"or it is going to change the direction we ought to be going now."

I believe that that type of analysis goes on in the Department of Defense. I hope it does—that is about as much as I can say about that topic.

Senator SANTORUM. That is not particularly reassuring to me.

Mr. ALDRIDGE. I did not think that I wanted it to be because I am not sure that——

Senator SANTORUM. I understand. You are new here. I am not going to hold you to that. [Laughter.]

But I am not exactly—I was not emboldened by your response.

Mr. ALDRIDGE. OK.

Dr. ETTER. I would add that one of the things about basic research that is important to remember is most of the time it is not obvious what the applications are going to be. So I think that is the point at which you begin to see how something is going to be useful, is when you can see the applications. Sometimes that occurs in basic research, but often it is not the case. It is after it moves further into more applied research.

I think the way that we try to make sure that we are positioned to take advantage of things that we do see is by looking at the designs of our systems and trying to use things like open standards, architectures that allow us to do insertion of new technologies.

I think there are things that we can do to our systems today that not only allow us to plan to use technologies we see that are perhaps 3 to 5 years off, but to position them for things from basic research. But most of the benefits from basic research really are things that are further off than the current decisions we have to make today, but it is looking at the environment of systems and the ease with which we can upgrade that may be one of the ways we are going to be able to allow ourselves to take advantage of that.

Senator ROBERTS. Let me say that was a very helpful and provocative series of questions, Senator, very helpful.

Our distinguished ranking member has a time problem. Would you like to add anything at this point?

Senator LANDRIEU. I just want to say that I am going to submit some additional questions for the record, but again, I just think this is a very important hearing. I really believe that the panelists from Kansas, Pennsylvania, Louisiana, and from other states and many of our universities have been part of this research.

I have to slip out, but I am going to submit my questions for the record, Mr. Chairman, and will be reading the transcript of this because we will use this as a foundation to build on the future. I thank you all very much.

Senator ROBERTS. Thank you, Senator.

Secretary Aldridge, I got a lawyer problem. [Laughter.]

You mentioned in your testimony last year that Congress did provide lab directors the direct hire authority of personnel, and the usual process of hiring could take anywhere from 3 to 18 months. It has taken more than that to get the authority to shorten that up.

This authority has not been utilized because apparently there is a disagreement between the acquisition folks and the personnel lawyers at the Department. Could you address this issue? How do we tap the lawyers so gently on the shoulder and say, "Move"? [Laughter.]

Mr. ALDRIDGE. I had a discussion just yesterday with the new Under Secretary for Personnel and Readiness, Dr. David Chu. I discussed this problem with him, and we will resolve it within the next few days. I think it will be resolved in a very favorable way.

We do want to implement this authority. We think it is necessary for our laboratories to get the very best talent. It is something that is short-sighted for us to have not exercised this sooner.

Senator ROBERTS. Mr. Secretary, you can certainly tell those folks that you had a very helpful discussion with the Chairman, soon to be ranking member of the subcommittee. [Laughter.]

If necessary, we can certainly stipulate anything that you suggest in legislation, and we want to get the damn thing done. Is that pretty clear?

Mr. ALDRIDGE. You are not very wishy-washy on that issue, sir, very straightforward. [Laughter.]

Senator ROBERTS. Mr. Secretary and Dr. Etter, last year Congress required the Department to report on possible innovative approaches which you might take to address the technology transition issue. We suggested in language that the Department review such processes as the budget and acquisition process in order to accelerate the transition, along the lines Senator Santorum has suggested.

We encouraged the Department to think of new approaches for providing what we call the timely transition of technology into the hands of the warfighter, such as a transition opportunity fund. Could you comment on what stage the report is in, and what sort of innovations the Department might undertake to deal with this issue?

Dr. ETTER. This is a report that is currently underway. It is not completed at this point, but we have tried to take into account the suggestions that you have given us.

As we look at technology transition, one of the things that I think is clear is that there is no silver bullet here. It is something that you have to look at from a lot of different perspectives and have a lot of programs that work this.

We do think having some kind of funds available to help transition programs that become very successful that are not in the palm process is going to be an important way to do that. We also think that there are ways of changing the funding process for our advance concept technology demonstrators that will also allow us to transition things that come out of that. So——

Senator ROBERTS. Well, that is the peanut that I am interested in. We will name it after Senator Santorum. It is a transition opportunity issue, in order to get it in the hands of the warfighter. That is the one I really think has a lot of possibilities. Any comments? All of us feel that if we do not have a fixed amount, as you get into what the vagaries of the budgeting are, that the fixed amount the 3 percent should stay.

But if you had a transition opportunity fund, and you could say to members who may be somewhat critical, if we are trying to establish priorities, say, "Look, we have a transition opportunity fund," this actually puts it in the hands of the warfighter.

I think that is justifiable. I think we could make that case. I think we could make it on the floor of the Senate if anybody wants. I do not know about the appropriators but——

Dr. ETTER. We agree. We are working to try to come up with a plan to do that. Thank you.

Senator ROBERTS. OK. Dr. Etter, the Department embraced the utilization of technology readiness levels. You referred to that earlier in your testimony. The theory, as I understand is, everybody involved in the development of the system will know the level of risk they are taking on when adopting a technology at a certain readiness level.

Now, here is the peanut again. The GAO reported last year that the Department usually—or the typical transitions technology at about technology readiness level three or four—in other words, that is when you transition it—the industrial transitions as I understand it from the GAO report is at approximately seven.

Now, my concern is primarily one of resources. The investment in the less expensive S&T phase of the process to mature it in technology and development, would appear to save money in the acquisition process. But does the S&T community have the adequate resources to develop the technologies to the later stages?

One of the things is if you are at three or four, then it goes to industry and the damn thing breaks, or something happens, or it did not work out quite, why can you not have it in seven so you have a more robust product, and you can see where you are headed? Then in the long run, you are not going to have such a scattered approach. You use more of a rifle shot, and it pays off. Am I right in that? You see where I am headed in this?

Dr. ETTER. Yes, I do, and I think your point is well made, that if we are going to do more of the risk reduction within the S&T Program, that there will have to be funds to look at how we are going to support that, whether it is actually still S&T funds or funds as you move into six/four, but it is going to require additional funding to make sure that we have mature technologies as we go to acquisition.

I think that there is another thing that will be involved in implementing this, and we are looking very closely in a task group at how we are going to implement this because this is a new requirement now that we are working on. There is also just a lot of time and effort spent in trying to do the evaluations of the TRLs themselves.

One of the things that will be important if this process is going to work in terms of helping project managers understand the risk of technologies that they want to use, is that we have to be able to assign these technology readiness levels consistently across the services. It also means that we have got to be able to assign them for not just hardware, but also for software. So we do see a number of challenges with this.

The funding issue that you brought up will be one of the challenges, and being able to consistently define the levels for technologies will also be important for us to look at.

Senator ROBERTS. Mr. Secretary, in the recent Defense news article, it was reported that you sent a memorandum to Department's research directors and the procurement chiefs to stop the practice of requiring or asking our defense companies to "supplement the Department of Defense appropriations by bearing a portion of the Defense contract costs." Why did you do that?

Mr. ALDRIDGE. Well, for the first time that I ever read a newspaper, it was correct. I did send a memo. We have found that through the years that there has been, as a result of underfunding some of our research and development activities, there was pressure placed on contractors to use their IR&D funds or even profits to help us through a transition period in the Department of Defense.

My view is: That is an unhealthy practice. We need a defense industry which is strong. If we are going to expect the best weapons systems in the world, we need to have a strong defense industry to produce those systems. I believe it was inappropriate for us to encourage the industry to fund programs that we had underfunded through the normal budget process.

I thought that the practice ought to stop, that if the Department of Defense could not afford to pay for a development program within its own budget and to rationalize it through the process of the Department of Defense and Congress, then it was not appropriate that we approached that program in that way. The idea of co-funding or using the IR&D funds of the industry to help us, I thought, was inappropriate.

As a result, they can now use their IR&D funds in ways that can help the Department by innovating things that we may not be thinking about. They can use their own talent to help the Department of Defense in ways that we perhaps may not have anticipated. That is the reason for IR&D, and that is the way it should be used.

Senator ROBERTS. That is a very strong statement. If you are going to force Peter to pay for the R&D Paul, or that that is what we used to do, and that is not going to be the fact anymore, basically you are saying that we should to fund it.

Mr. ALDRIDGE. Yes, sir.

Senator ROBERTS. All right. Senator Allard.

Senator ALLARD. Mr. Chairman, I do not think I have any more questions.

Senator ROBERTS. Senator Santorum.

Senator SANTORUM. Just a followup to that: Do you see that as creating an incentive for the private sector to do more research funding? I mean, more funding—you gave me the sense that they are sort of going to be off doing their own thing. Is there any coordination that you envision now that you have freed up this pot of money?

Mr. ALDRIDGE. Yes, sir. We watch what they do with their IR&D. In fact, in some cases, contractors come and ask us how they should spend their money in the best way for long term. We are not blind to how they spend their resources, but in some cases they have some better ideas of how to spend the money than we do perhaps.

Senator SANTORUM. Do you expect that to maybe result in even more leveraging of funds? In other words, them putting even some more money in as a result of that?

Mr. ALDRIDGE. That is their choice at this point in time. If they see—the one exception to this rule is that if there is a very strong commercial application for the product, we might think about allowing co-funding.

A good example is the expendable launch vehicle where, in fact, the Department of Defense saw that there was a valuable commercial variant of that, and so we did co-fund. There may be those cases that would be quite appropriate, but not in every case.

Yes, I believe that if the industry saw that this IR&D, they found a great product, and it may make them very competitive in the future, they maybe would invest their own money into making them more competitive. So we win all around. We have a stronger industry which is better for us. It is a more competitive industry, and it is one that I think we all want.

Senator SANTORUM. Thank you, Mr. Chairman.

Senator ROBERTS. Dr. Etter, do you want to give us a little advance on the inner advanced electronics initiative that you are introducing in the fiscal year 2002 budget so we can go in a resolved and well-done—[Laughter.]

Dr. ETTER. I would be glad to give you a sense of the areas of priority in that. As you look at electronics, it is clear that there are lots of areas where commercial industry is way ahead, and what we need to do is just figure out how we can leverage off of that. But there are some areas that DOD is very interested in that commercial industry is not going to invest in. We have identified four of those.

We think that, for example, RADHARD electronics is something that is very critical to DOD, particularly as we make the move into space. This is an area where there is not a commercial market. So DOD has to take a special interest in that.

We currently have some activities. We have two fabrication lines that do RADHARD electronics, but one of the problems here is that they are about two and a half generations behind the commercial industry. So we need to look at this area not only in terms of providing DOD support to make sure the capabilities are there, but we really need to look very seriously at bringing these up to perhaps a generation behind commercial industry so that we have the kinds of capabilities that we really need to do the kinds of things we want to do in terms of space assets.

Another area has to do with radio frequency electronics. This has two parts that are particularly important to DOD. One is in vacuum electronics, again an area that DOD is the main group that has an interest in this. This is an area that the Navy in particular has a wide use of vacuum electronics in some of its radar systems.

Another area in this is wide-band gap. This is looking further out. This is certainly one of our basic research areas. It is one in which we need to do some of the initial research to the point where commercial industry will pick it up. So it is not something we need to stay in forever, but we need to do some of that initial work in it.

So those are three of the areas that fall in that. There are a couple of others in terms of mixed signals that are important for us to do, and some of the infrared areas. So we have put together an initiative that particular identifies the things DOD has an interest in.

We hope that with the priorities that Secretary Rumsfeld is going to be naming, that we will be able to look at that as part of the funding in the S&T program.

Senator ROBERTS. That is a great segue. We did not plan it that way, but it is a great segue to Senator Bob Smith's question which I have here. I would like to ask it at this point with regards to RADHARD electronics. Following my own rule of thumb to prevent me from putting a dollar into the fish bowl that we did not really bring out today: Radiation Hardened Micro Electronics Industrial Base, RADHARD.

Question on behalf of Senator Smith: Are there sufficient funds in fiscal year 2002 and the out years to fund RADHARD process development, to provide appropriate capital equipment, and to design advanced electronic devices necessary to modernize this critical industrial base?

Dr. ETTER. Well, of course, we cannot talk numbers here, but we certainly have been talking about that very issue, and we hope that that will be one of the things that will be part of our new budget.

Senator ROBERTS. I am sure that Senator Smith will follow up on that, as we all will. He has a follow-up question. What is your strategy to maintain robust competition for development and production of RADHARD electronics?

Dr. ETTER. Well, the competition area really comes from having two different fabrication lines. So I think the essence there is that there are real benefits to having the competition of two lines. We recognize that and hope that that will be something we can take into account as we look at the budget to support this.

Senator ROBERTS. What do you need from Congress for the Etter Initiative?

Dr. ETTER. Well, I think the funding that Secretary Aldridge has said he is going to support within our program is the kind of support we need to be able to do that.

Senator ROBERTS. We will call it the Bob Smith/Rick Santorum Initiative. We better find us some help from the Majority as well.

Thank you so much for your testimony. Thank you for your service to our country, Dr. Etter. Welcome aboard, Secretary Aldridge.

We will ask the second panel to come up at this time.

Mr. ALDRIDGE. Thank you, sir.

Dr. ETTER. Thank you. [Pause.]

Senator ROBERTS. The second panel is comprised of the Science and Technology representatives of the military services and also DARPA.

As the witnesses are aware, the purpose of this hearing is different from past years. Today, we will hear about investment in "leap ahead" technologies, the transformation efforts underway within the services' Science and Technology Programs, and the transition of the revolutionary technologies in the hands of the warfighter.

Without the budget, however, this subcommittee is unable to review in detail the commitment by the new administration to the Science and Technology Program. A strong, stable investment in Defense Science and Technology remains a priority of the subcommittee. In addition, we must ensure the warfighter has a capabilities over match well into the future. That is why in the absence of a budget it is still important to discuss the investment in truly revolutionary and "leap ahead" technologies.

I would like to welcome our witnesses to today's hearing. We will hear from Dr. Michael Andrews about the Army's transformation efforts and the Future Combat Systems approach. I look forward to hearing what a "system of systems" is and what that approach is, and the definition of "system of systems," and how it is truly an out-of-the-box thinking.

The Future Combat Systems aim to be an ensemble of capabilities, a group of systems working in collaboration. It is ambitious, and is planned to lead the future in an Objective Force.

The subcommittee now looks forward to hearing about the partnership the Army has formed with DARPA to implement the Future Combat Systems.

We want to welcome Admiral Jay Cohen. This year, the Navy finished an ambitious process of realigning its Science and Technology priorities. The subcommittee anticipates receiving an overview of this transformation process, and the division of the S&T Program into two areas, the long term grand challenges and the more immediate future naval capabilities.

The Navy has realigned its funding priorities to correspond to the newly identified technological capabilities, thereby focusing its effort in the most important research areas. We anticipate hearing more details about which technological challenges the Navy has identified as necessary to achieving these capabilities. I am also interested in hearing what efforts you have taken for force protection following the attack on the U.S.S. *Cole*.

Dr. Don Daniel will testify on behalf of the Air Force. The subcommittee is particularly interested in hearing from you, Dr. Daniel, on the Science and Technology Planning Initiative now underway within the Air Force. I might mention that everyone here is well-aware of the issues confronting the Air Force Science and Technology Program, and the subcommittee's past concern about the lack of support for the program.

It is critical that a real commitment to the long-term technological superiority required by the Air Force be provided in several key areas, including a renewed emphasis on space and missile defense. I understand that the Air Force has taken a very long look at the planning process mandated by Congress in last year's National Defense Authorization Act. I know that you are currently about halfway through the process, and real progress is being made.

Also, I understand fundamental changes will occur no earlier than next year. I hope to hear more about that process today and the ownership taken by the Air Force leadership to turn around that serious deficit in its Science and Technology Enterprise.

I would like to be optimistic about the process you are undertaking, Dr. Daniel, but do not be surprised if I remain skeptical until the process is finished, and future budgets are received and reviewed.

Finally, I would like to welcome Dr. Jane Alexander, Acting Director of DARPA. The subcommittee looks forward to hearing about the "leap ahead" technologies that DARPA is engaged in, and the technology transition of these innovations to the warfighter community. You heard the earlier statements, I am sure.

We will begin with Dr. Andrews, followed by Dr. Daniel, Admiral Cohen, and then we will close with Dr. Alexander.

Now, after all those very lengthy questions to discuss at great length your future, we would like for your statement to be around 5 minutes so there will remain time for questions and answers.

I think you know what we call "show and tell." Senator Santorum has offered to try on the helmets and the goggles and any other things. [Laughter.]

If things fly, he can be in charge of that as well. [Laughter.]

So the liaisons will bring the displays to us and we will proceed with our first witness.

STATEMENT OF DR. A. MICHAEL ANDREWS II, DEPUTY ASSISTANT SECRETARY OF THE ARMY FOR RESEARCH AND TECHNOLOGY AND CHIEF SCIENTIST

Dr. ANDREWS. Thank you, Chairman Roberts and Senator Santorum. Thank you for this opportunity to discuss how the Army's Science and Technology (S&T) Program is focused on accelerating the pace of the Army Transformation. I have previously submitted a written statement. I would like to summarize my remarks this afternoon.

Senator ROBERTS. Certainly.

Dr. ANDREWS. We are developing the fullest range of technologies to provide materiel solutions that will blur the traditional distinctions between the Army's heavy and light forces and, at the same time, increase their strategic responsiveness, and very importantly, reduce our logistic demands for those kinds of forces.

Our goal is to field this capability for the Objective Force by the end of this decade, a very challenging time frame. It is my privilege to report to you that the Army's scientists, engineers, and our industrial and academic partners are committed to making the transformation a reality.

The most vivid example of this commitment and our single largest S&T investment for the Army S&T Program at about $500 million per year, is the Future Combat Systems (FCS) Program.

Importantly, this "leap ahead" capability is being addressed in a strong partnership with DARPA. FCS is also a very clear example of the spiral development that you mentioned earlier; users, system developers and designers, and technology developers working together to give us the first capability for a fielded effort, followed closely with technology insertions.

We believe that the Objective Force soldiers in this 2010 time frame, equipped with the Future Combat Systems, will be capable of dominating across the full spectrum of operations, from peace time engagement through major theater warfare.

Our warfighters from the Vice Chief of Staff established a design crucible for FCS, of 20-ton class or lighter. Abrams, of course, is about 70 tons, but a world-class killer and survivor.

This demands that our Future Combat Systems be achieved with a "systems of systems" approach as you mentioned. This provides us a "leap ahead" in force capability with unprecedented lethality, survivability, integrated on the move command and control, as well as full situational awareness.

It is not a platform. The FCS is not a platform. It is a system of battlefield capabilities in which the whole exceeds the sum of its parts. That is the real difference with "system of systems," for the whole to exceed the sum of its parts.

Fielding FCS will represent a true paradigm shift for the Army and how it fights, perhaps as significant as the introduction of the tank or the helicopter. It is that significant. On behalf of our soldiers, though, I want to really thank Congress, especially members of this committee, who last year supported the FCS program and the increases we needed.

In my submitted written testimony, I have described many important areas of innovations. In the area of armaments, a multirole cannon that can do both direct and indirect fire, on the move, and less than 20 tons; a compact kinetic energy missile that moves at about a mile and a half a second, and has the lethality to take on the next generation of tanks.

I also have talked about survivability, active protection systems, as well as smart armors that protect our tanks and our soldiers; and finally, in terms of C^4ISR, the ability to have on the move command and control for our systems.

But what I want to do is give you a very clear example of the innovative thinking going into all key Objective Force concepts. It is that synergistic mix of manned and unmanned systems. You talked about that earlier, as well as Secretary Aldridge.

To enable these innovations, we are pursuing a prudent balance between higher and lower risk technologies for the development of ground vehicles, or Unmanned Ground Vehicles (UGVs) to support FCS and other systems of the Objective Force. Let me describe this balance through three technical approaches to introduce robotics on the battlefield.

First, at the lower end of technical risk, the Army is conducting a Robotic Follower Advanced Technology Demonstration Program. This program will develop and demonstrate near-term technology that permits a UGV, unmanned ground vehicle, to follow virtual bread crumbs, of a manned system that is in front of it. Typical follower missions then that we can provide are logistics resupply, medical evacuation, non-line-of-sight weapons carriers, as well as security for our troops.

Second, for the mid-term we are pursuing a higher risk Science and Technology Objective Program to provide Semi-Autonomous Robotics through improved perception and command and command capabilities. This will expand the UGV mission such that we can take on an unmanned scout capability, one of the tougher points. Tell it to go from “a” to “b” on its own, find the target, locate where that is exactly, and communicate where you are and where it is without being destroyed.

The third, and finally then, to enable the near autonomous—getting as autonomous as we can get with UGV systems—the highest risk and perhaps the highest payoff in robotics work is being done as part of the DARPA/Army Collaboration Effort. DARPA is pursuing advanced technology for UGVs to increase mobility and provide alternative perception and control technologies.

Now in addition to these ground vehicle robotic systems, we also have Unmanned Air Vehicle concepts. One of these on the table as you can see, the little round circular piece, is what is called an Organic Air Vehicle, adducted fan rotorcraft. It can provide extended range, stand-off sensors for the elements of FCS, to see before being seen.

The current capabilities for this rotorcraft are capability of vertical takeoff as you can tell; it hovers; horizontal flight capability at

55 miles an hour, and up to 30 minutes of endurance, already tested. Potential missions here obviously include on-demand aerial reconnaissance for the FCS in restrictive terrain such as under trees or in urban environments. This also is being developed under the DARPA/Army partnership.

Senator ROBERTS. How much does that weigh?

Dr. ANDREWS. Ten pounds. It carries a payload of about like 76 grams or so, 75 grams, a very small sensor——

Dr. ALEXANDER. It is a scalable design so it can be made at a larger size if a larger payload is needed.

Dr. ANDREWS. Very key. I have just described some of those for the future. Let me now talk to you about two recent successful technology transitions, talking about the past that has certainly paid off here.

First on the table, you see the Objective Individual Combat Weapon (OICW). That is the armament sitting in front of you. This is the product of an Army Advanced Technology Demonstration Program that was just transitioned to the program management side. This is a full-scale model of this objective individual combat weapon, weighs the same as the actual ATV product.

It provides the individual soldier a new capability, to shoot an enemy in a hide position, in a foxhole, or behind a wall through a window, with its air bursting of 20 millimeter round. This is done by using a laser range finder to provide the smart munition and the front end for this round, the exact range to detonate.

The bottom line, compared to the current M–16, grenade launcher, the OICW provides eight times the fire power at twice the range. This allows our soldiers to see first, act first, and finish decisively, leaving the enemy no place to hide.

Another successful transition from the Army S&T Program addresses the number one cause of combat fatalities, blood loss. On the table in front of you are also two small plastic samples. Those are fibrin bandages. This was successfully transitioned from the Army Medical S&T Program. It is a cotton fiber material that—can somebody show that?

Senator ROBERTS. Just grab the fibrin bandage. Do not grab the weapon. [Laughter.]

Dr. ANDREWS. This is a cotton fiber material that has been impregnated with two human blood clotting proteins. The bandage will stop bleeding within 2 to 3 minutes.

If you think about a bullet wound, or a major surface wound, or if you had a hole through your arm, you plug it in and stop the bleeding, again, within 2 to 3 minutes. While the obvious and primary purpose of this fibrin bandage is to save soldiers' lives——

Senator ROBERTS. Doctor, why does this say, "not for use in humans"? [Laughter.]

Dr. ANDREWS. Prototypes, not Food and Drug Administration (FDA) approved yet. Part of our process in the Army Medical S&T is to go through FDA.

Senator ROBERTS. But okay for the family dog here, I guess. [Laughter.]

Dr. ANDREWS. We go through FDA which takes us——

Senator ROBERTS. How long does that take?

Dr. ANDREWS. That is almost as long as our acquisition cycles. It takes a good 7 years to get through the FDA.

Senator ROBERTS. Seven years to get this damn thing done?

Dr. ANDREWS. Well, once we get them through the technology piece, then they take their time. I mean, we are talking about using this on our soldiers, and FDA takes their time to make sure there are no problems.

Senator ROBERTS. If you are trying to stop a bleeding wound, it seems to me that is a little higher priority than gulping down a pill or two for whatever ails you.

Dr. ANDREWS. FDA is outside our control, obviously, and their priorities.

Senator ROBERTS. My Lord, we got Viagra before we could get this thing. [Laughter.]

Dr. ANDREWS. It will be there before the end of the decade, though.

Senator ROBERTS. Well, we need to take a look at that. That is ridiculous. I guess that is outside of our jurisdiction. I do not know.

How many of those prototypes do we have of the Objective Individual Combat Weapon?

Dr. ANDREWS. That's up there.

Senator ROBERTS. OICW.

Senator SANTORUM. That is the gun.

Senator ROBERTS. Yes, I know that. I am not—[Laughter.]

Senator SANTORUM. Are you still talking about FDA? [Laughter.]

Senator ROBERTS. No, I am done with FDA. I am upset with the FDA. We will raise hell about that later. [Laughter.]

But, how many prototypes do you have of this? [Indicating]

Dr. ANDREWS. We built one prototype.

Senator ROBERTS. That is it?

Dr. ANDREWS. That is it. Now we are into the PM, and they are building some new prototypes. They have just been in it for 1 year. We built our demonstration unit. Again, that is the issue of limited resources. We carried two contractors as long as we could, and then did a down select.

Senator ROBERTS. If so, in fact, this is the weapon of the future as described in the combat situations that you have described and this is acceptable to the Services, I am assuming the Army, and the Marines, and others, how many years away are we from that?

Dr. ANDREWS. This is roughly at the fiscal year 2009, fiscal year 2008 time frame for introduction, first unit equipped. So that is about 7 years down. We are just now entering——

Senator ROBERTS. How do we speed that up?

Dr. ANDREWS. Resources.

Senator SANTORUM. So it is a resource question. It is not a technology question.

Dr. ANDREWS. It is a resource question, yes.

Senator ROBERTS. It is not technology as the Senator has indicated. It is a resource situation.

Dr. ANDREWS. In this case, this one is less science and technology. It is now in the acquisition, and the acquisition has limited resources.

Senator ROBERTS. Why can that transition fund not be used? That is exactly what we asked Dr. Etter and the Secretary. Why could that transition fund not be—if you want to hold that up on the floor of the Senate. [Indicating] [Laughter.]

I do not know—if we really want to take over, that might be a way. [Laughter.]

Senator ROBERTS. But, that is just too slow. I am sorry. Go ahead.

Senator SANTORUM. Well, that is the classic problem with all of our acquisitions. I mean, they just take too darn long.

Senator ROBERTS. Right.

Dr. ANDREWS. There are many parts to that problem. One is the amount of testing that has to go on. Since our soldiers will carry these, we have to make sure that everything is——

Senator ROBERTS. How much does that weigh?

Dr. ANDREWS. Too much. That is about 14 pounds, and trying to go down.

Senator ROBERTS. Yes, that is too much.

Dr. ANDREWS. Right. It is on a diet right now. Everything they are doing is to drive that weight down as well as working on improving the cost of the munition that goes with it, smart round.

Senator ROBERTS. OK. I am sorry to interrupt you. Go ahead.

Dr. ANDREWS. OK. Let me back up to the Army's vision.

Senator SANTORUM. Let me just—so part of it is technology.

Dr. ANDREWS. Yes, sir.

Senator SANTORUM. You are telling me it has to go on a diet. I mean, if you knew how to do that, you would do it. So the problem is not just money. It is money and technology.

Dr. ANDREWS. Money and technology, but most of the technology is mature technology outside the S&T world. So it is the PM world of reducing weight of materials, going more to composites which are off-the-shelf, more design changes by the contractor, drive the weight down.

Senator ROBERTS. OK.

Dr. ANDREWS. Since the Army's vision was announced in 1999, we have significantly reshaped and sharpened the focus of our advanced technology development in applied research investments for transformation Objective Force.

Also on the table, I have the 2001 Army Science and Technology Master Plan. Those are the two large documents that you see sitting up there. [Indicating] This is the first Army S&T document that really is a capstone for capturing all of the changes to meet our transformation efforts.

Now critical to the Army Transformation to the Objective Force, we have a corporate technology to readiness decision in April 2003. This is when our Chief of Staff, and the Secretary, and DARPA will make a decision to launch that "system of systems" demonstration area, in 2003 and go through 2005.

Because S&T is critical to the Army's Transformation, last summer we established monthly Science and Technology Reviews with the Chief of Staff of the Army and the Army's four star commanders to provide broad guidance on warfighter needs and to assess our progress in satisfying those needs.

In addition to maturing and transitioning technologies as rapidly as possible, we have maintained a longer term perspective with our basic research program. We have increased efforts in microturbine technology. This will allow us to be more efficient in electric power for the individual, and reduce the current demand we have for the number of batteries soldiers have to carry.

We are also establishing a nanotechnology center to address Objective Force survivability. The center will focus on applying nanoscience technologies from universities, industry, and Army labs to achieve the material breakthroughs in soldier's stealth and ballistic protection, and reduced weight.

We are also exploring state-of-the-art simulation technologies at the Army's Institute for Creative Technologies at the University of Southern California. We are leveraging the creativity of the entertainment and game industries to create compelling immersive environments for training our soldiers, increasing the likelihood that when the Nation sends soldiers into harm's way, they will accomplish the mission and return safely.

Now, of course, we cannot achieve these goals without top caliber scientists and engineers who develop our technologies for the soldiers. Recruiting and retaining S&Es is a challenge across DOD as Secretary Aldridge has already testified.

Last month, I convened an Army-wide S&T Leadership Summit. One of our tasks was to identify innovative approaches to recruiting, retaining, and refreshing the Army S&E workforce. We will be sharing these insights across the Department. I want to assure this subcommittee that I am committed to ensuring the quality of our S&E workforce. Our soldiers really depend on it.

In closing, the Army S&T community has stepped up to the technical challenges necessary to enable the Army's transformation. We have energized all of our resources and are committed to making the Objective Force a reality. Your continued support is very welcome and critical to this Army transformation effort.

Thank you.

Senator ROBERTS. All right.

[The prepared statement of Dr. Andrews follows:]

PREPARED STATEMENT BY DR. A. MICHAEL ANDREWS II

INTRODUCTION

Mr. Chairman and Members of the subcommittee, thank you for the opportunity to appear before you to discuss the Fiscal Year 2002 Army Science and Technology (S&T) Program and the significant role S&T has in the Army Transformation. It is my privilege to represent the Army leadership, the members of the Army S&T community, and America's soldiers who rely on us to provide them with the capabilities they need to execute our National Military Strategy throughout the world.

I thank the members of this committee for your important role in making today's Army the world's preeminent land combat force. I also thank you for your assistance in our transformation efforts. Your continued advice and support are vital to our success.

TRANSFORMATION

The Army is changing and Army S&T has accepted the challenge of enabling this change. We are transforming today's Army from a Cold War Legacy Force to an Objective Force. This force will provide early entry capabilities that can operate jointly, without access to fixed forward bases, and still have the power to win campaigns decisively. The Army's Transformation will initially augment, and eventually replace, today's Legacy Forces which are too heavy or lack staying power.

We are an Army between wars, and we are challenging all the assumptions about what conflict may be like in the future. We are doing this to ensure that our future soldiers have the capabilities necessary to accomplish the full spectrum of operations they will face in the 21st century. Our future force, the Objective Force, will be more responsive, more deployable, more agile, more versatile, more lethal, more survivable, and more sustainable than our present force. The Objective Force will be strategically dominant, capable of placing a combat capable brigade on the ground anywhere in the world within 96 hours, a division on the ground within 120 hours, and five divisions in theater within 30 days. These are ambitious, but achievable, goals.

THE ROLE OF ARMY S&T

The Army S&T program is central to enabling the new vision and is on the critical path of the transformation leading to the Objective Force. We are committed to providing the technology to accelerate this transformation. The Army has challenged us to answer some very tough questions about achieving the Objective Force-desired capabilities. As General Shinseki has stated at a recent Association of the United States Army meeting, "We are asking the science and technology community and industry to deliver capabilities that will help break the Cold War mindset we all carry with us." He made specific challenges in that same speech:

- I would like to know whether we can design (combat) systems that can't be hit.
- I want range overmatch: I want to see farther than the other guy and engage well outside his lethal envelope.
- I want early, discrete targeting.
- I want to pull the trigger first every time and kill a target each and every time I pull the trigger, and I want to do it at smaller calibers.

To meet these challenges, the Army's S&T community has focused and sharpened its efforts. The Army has also partnered with the Defense Advanced Research Projects Agency (DARPA) to demonstrate an entirely new land combat capability called the Future Combat Systems (FCS). FCS is not "a platform." It is a system of battlefield capabilities in which the whole exceeds the sum of its parts.

FCS represents a true paradigm shift in how we fight—perhaps as significant as the introduction of the tank or the helicopter. Fielding FCS will be equivalent to making heavy forces lighter and lighter forces more lethal, in addition to reducing logistics demands. Some of the key challenges include:

- **Survivability:** Survivability is the primary technology challenge because our combat systems must weigh less than 20 tons to be rapidly deployable. This forces us to find new ways to protect our soldiers. To survive a first round engagement with 21st century threats, individual FCS platforms will require advances in Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C^4ISR) and platform protection systems. Overall force survivability will require unprecedented battlespace situational understanding, stand-off threat detection, and neutralization capability. Options under development include advanced communications and sensor systems that will increase situational awareness and allow us to "see first" and farther than the enemy; active protection systems which are designed to degrade, deflect or defeat incoming threats before they can hit our vehicles; signature reduction techniques that will make us harder to see and therefore harder to hit; and lightweight armor that weighs ¼′ of the current armor, but provides the same protection.
- **Lethality:** Although our systems will be lighter weight, they must maintain the lethality overmatch of current systems while supporting the shortened timelines associated with future threat environments. Required capabilities include lethal and non-lethal, line-of-sight and non-line-of-sight, gun, missile and directed energy weapons that will provide for the destruction or incapacitation of multiple targets. Options under development include the precision and loiter attack missile systems that will allow us to conduct precision engagements against the enemy at much greater ranges than he can; lightweight, lower caliber guns and ammunition capable of precision direct and indirect fire at long ranges, potentially enabling us to combine capabilities of the traditional tank and artillery piece into one system; extremely lethal compact kinetic energy missiles that ensure overmatch against advanced protection systems, and directed energy systems like lasers and high-power microwaves for lethal and non-lethal applications.
- **C^4ISR:** Network centric operation is the linchpin for FCS and the Objective Force, providing the foundation for comprehensive situational awareness and the capability for instantaneous prioritization, distribution and engagement of multiple threats. On-the-move, distributed command and control, multi-function sensors and sensor fusion algorithms, and development

of a seamless Tactical Internet among leaders, soldiers, platforms, and sensors are critical to achieving these goals. Options under development include digital, secure on-the-move communications for collaborative planning and execution, positive command and control, and shared situational awareness; enhanced radar and sensor systems for longer range detection, accurate identification and precise localization; information assurance to counter information attack and avoid deception, denial and disruption; and aided target recognition to reduce reliance on the human-in-the-loop and increase likelihood of engagement against high-value targets.

- **Power Generation & Management/Electric Propulsion:** The Objective Force will require efficient power generation and management systems to remain lightweight, but still function at a fraction of the logistics burden of the current force. Fortunately, the Army can leverage commercial investments, and is engaging with industry to achieve mutual development benefit. Options under development include hybrid electric drive for high acceleration, silent operation, design flexibility and increased fuel efficiency; fuel cells for efficiency, quiet operation, reduced environmental impact and potential water generation; advanced diesel engines scaled for FCS-class vehicles with higher power density and greater fuel efficiency; low power demand electronics to increase energy efficiency; and efficient power management designs.
- **Human Engineering:** Future soldiers will face increased challenges because of the variety of missions and complexity of tasks that they must accomplish. We must minimize this complexity and ensure our soldiers are trained and ready to function on the battlefields of the future. Options under development include human/machine interface designs that decrease task complexity and execution times, improve performance levels, and minimize physical, cognitive, and sensory demands; associate systems to complement human operators, offload routine tasks and enhance high priority task performance; and embedded/deployable training and mission rehearsal environments to maximize warfighter readiness for the full spectrum of operations in rapid deployments.

UNMANNED SYSTEMS

The Army supports the Congress' desire for fielding substantial unmanned capability among future operational ground combat vehicles and is aggressively addressing the technology, costs, risks and operational issues. To achieve that end, the Army has implemented a bold robotics technology investment strategy to provide the critical options needed to create opportunities for insertion of unmanned capabilities into the Objective Force. The Army has structured the FCS program with phased upgrades to support the introduction of progressively more robust unmanned ground combat capabilities.

As part of its on-going partnership with DARPA, the Army is sponsoring the development of FCS concepts that involve significant unmanned capabilities. The Army strategy is to initiate the incorporation of substantial unmanned capabilities through the FCS program. The synergistic integration of manned and unmanned systems envisioned for the Objective Force will expand the envelope of capabilities at the leader's command and reduce the threat to our soldiers, taking them out of harms' way. The Army vision for the FCS and the Objective Force incorporates unmanned systems as a key element for both ground and air operations. The Army is currently developing the fundamental technology to enable these systems, both on its own and in collaboration with the DARPA.

The collaborative Army/DARPA FCS program will define and validate FCS design and operational concepts, including the role of unmanned ground vehicles (UGVs) and unmanned air vehicles (UAVs). Potential unmanned functions include:

- Remote sensing (UGV scouts, UAVs)
- Communications relay (UAVs)
- Unmanned weapons carriers for line-of-sight and non-line-of-sight fires (UAVs and UGVs), and
- Unmanned logistic support vehicles (follower UGVs).

As part of the Army/DARPA program, DARPA is pursuing advanced technology for UGVs to increase mobility and support enhanced perception capabilities. While promising, these technologies may not be sufficiently mature to be inserted for the initial fielding of FCS. The Army is, therefore, pursuing a complementary lower risk UGV approach for FCS. Building on past successes, the Army is pursuing a dual-track approach for development of UGV technology, consisting of a Robotic Follower

Advanced Technology Demonstration (ATD) and a Semi-Autonomous Robotics for FCS Science and Technology Objective (STO).

The Robotic Follower ATD will develop and demonstrate near-term technology that permits unmanned systems to follow a path "proofed" by a manned vehicle. The unmanned system may follow by as much as a minutes, hours or a day later. The potential for new obstacles, such as other vehicles, civilian traffic, or battle damage will still require substantial development of perceptual capabilities. Follower technology will enable the use of unmanned vehicles for logistics missions, as non-line of sight weapons carriers, and to provide rear security for troop formations, among other capabilities.

The Semi-Autonomous Robotics for FCS program focuses on the development of more capable mid-term technology systems that are able to maneuver without substantial human intervention. The development of perceptual capabilities will permit unmanned vehicles to "understand" the environment, not only in terms of trafficability, but also tactically. The creation of the algorithms required for unmanned systems to employ tactical behaviors, analogous to the tactical judgment employed by soldiers, are a key part of this STO. The substantial, though still somewhat fragile, autonomous mobility capabilities recently demonstrated during troop-led experiments in relatively rugged terrain at Fort Knox, KY, underscore both the attainability and promise of the technology.

Additional Army technology investments that have direct relevance for FCS and the Objective Force are being made with DARPA. They include the Organic Air Vehicle (OAV) and a UAV rotorcraft with a large payload, long endurance and a vertical take off and landing capability (the A–160 Hummingbird), advanced command, control and communication technologies, and novel sensor systems. These technologies hold the potential to permit the FCS, and its associated dismounted forces, to operate in complex terrain by exploiting organic, non-line-of-sight fire capabilities through remote sensing and communications relays.

OTHER S&T PRIORITIES

Beyond the FCS, our S&T program must continue to support the full range of capabilities required for the remainder of the Objective Force. Some key areas of investment include:

- Objective Force Warrior: Integrated soldier system of systems to provide leap-ahead capabilities for the dismounted soldier with dramatic weight and power reduction. The system of systems will provide seamless connectivity with other personnel, weapon systems, FCS, and robotic air/ground platforms to achieve overmatch for the full spectrum of future operations.
- Medical Technology: Individual health monitoring, new medical and dental preventive and treatment modalities, including, vaccines and drugs against malaria, hemorrhagic fever, and scrub thyphus, will significantly reduce Disease and Non Battle Injury (DNBI) casualties and increase return to duty, thereby reducing the medical footprint and the attendant logistical requirements. Innovative products for far-forward stabilization and resuscitation, hemorrhage control, and minimizing neural injury will push advance care forward to the point of injury, decrease the mortality rate, reduce return-to-duty delay rate, and make extended evacuation times possible.
- Advanced Simulation: Modeling and simulation technology, such as an innovative partnership with the entertainment and game industries through the University of Southern California (the Institute for Creative Technologies or ICT) to accelerate the development of compelling immersive environments for training, mission rehearsal, and concept development. Another project, the Joint Virtual Battlespace (JVB) program, is an enabling technology for evaluating how FCS contributes to the total capability of the Objective Force, and how the Objective Force plays in a joint force. JVB, combined with virtual prototyping, also could provide an effective means for performing Operational Test and Evaluation without the need for numerous hardware test articles. This could result in significant time and financial savings in the Army Acquisition Process.
- Rotorcraft Technology: As the DOD lead for Rotorcraft Science and Technology, the Army is investing in the critical technologies that could provide heavy (up to 20 Tons) and semi-heavy (12 Tons), intra-theater lift to the Services, and armed unmanned platforms for combat reconnaissance. These technologies also could upgrade the current Army Aviation Fleet for heavier loads and reduced logistical burden.

• Basic Research: Investment in knowledge and understanding of fundamental phenomena to enable future technological development; includes support for academic research through the Single Investigator Program, University Centers of Excellence, University Affiliated Research Centers (UARCs, such as ICT), and the Collaborative Technology Alliances (CTAs, formerly known as Federated Laboratories). A specific new thrust in this area is the establishment of a Nanoscience UARC focusing on the application of emerging nanotechnologies to enhance future warrior survivability.
• Micro electro-mechanical System Inertial Measurement Unit (MEMS IMU): The Army has recently solicited 50 percent-cost share proposals to develop a low-cost, gun hardened and high accuracy MEMS IMU for gun-launched guided munitions, tactical missile and other military applications. The focus is to produce a MEMS IMU that will be bought by the DOD in bulk, thereby giving the economy of scale necessary to yield an inexpensive unit price. The goal is a military tactical-grade IMU that meets 90 percent of DOD munition and missile needs at a low-performance unit price, available from two, or more, commercial contractors.
• High Energy Lasers: The Army S&T program continues to investigate high energy solid state laser technology options for potential application on the tactical battlefield. In this effort, we are seeking to identify the most promising solutions to ensure speed of light engagement and laser weapon lethality throughout the spectrum of battlefield environments of weather, dust and obscurants.

CONCLUSION

Since the Army Vision was announced in October 1999, the Army S&T program has been re-shaped and focused to speed the development of those critical technologies essential to Transform the Army into the Objective Force. The Army S&T community has accepted the challenges and has energized all of its resources to meet them. We are accelerating the pace of transformation of The Army!

Senator ROBERTS. Dr. Daniel.

STATEMENT OF DR. DONALD C. DANIEL, DEPUTY ASSISTANT SECRETARY OF THE AIR FORCE FOR SCIENCE, TECHNOLOGY AND ENGINEERING

Dr. DANIEL. Thank you, Mr. Chairman, Senator Santorum. I very much appreciate the opportunity to be here today.

In 1944, General Hap Arnold said, "The first essential of air power is pre-eminence in research." That statement was true in 1944, and it is just as true today in the world that we find ourselves. By continuing our investment in a broad and balanced selection of technologies, the Air Force will retain its dominance of air and space in future conflicts.

Sir, as you mentioned earlier, I am happy to report and give you an update on our S&T Planning Review that we have undertaken in response to Section 252 of the National Defense Authorization Act. We have approached this review enthusiastically, and we have received outstanding participation from not only the Air Force S&T community, but the requirements, planning, logistics, and user communities as well.

We have over 250 people involved in this review now. About 140 of those are S&T folks, about 60 are from the requirements, to plans, and logistics communities, and about 50 are from the user or warfighter communities, all involved in this very large activity.

As you required us to do, the S&T planning review will identify the short-term objectives and long-term challenges of the Air Force S&T Program. The review has been divided into three distinct phases.

Phase I focused on identifying the objectives and challenges at the top level. This work has largely been accomplished in the January through April time frame. We essentially completed it last week, but I briefed the Air Force Council which is chaired by the Air Force Vice Chief of Staff, and these objectives and challenges were subsequently approved by the Council.

Phase II concentrates on in-depth investigations and analyses of the work that needs to be accomplished in order to meet these short-term objectives and long-term challenges.

Phase III will complete the review with an outbrief to the Secretary of the Air Force, and subsequent communication of the results to the Secretary of Defense and the Comptroller General. We also are maintaining contact with the GAO at periodic times as we go through the review, as well, so we do not wait until the end of the review and show them the results.

Another activity we have undertaken I would like to speak on for a few moments are Science and Technology Summits. There has been a significant increase in the involvement of the warfighting commands and senior Air Force leadership in S&T planning, programming, and budgeting. We have established semiannual S&T summits where the Secretary of the Air Force, the Air Force Chief of Staff, all of the four star generals in the Air Force, and other senior leaders in the Air Force review the S&T portfolio.

The first two reviews resulted in increased emphasis for research in sensors and information technology to advance our ability to find and attack targets under trees, and accelerated materials development for improved laser eye protection devices, an accelerating of development for the joint battle space infrasphere, and for completing important beam control demonstrations for our directed energy program.

I might add that our next S&T summit will occur at the conclusion of our S&T planning activity. So, again, with the Secretary, and the Chief, and all the four stars, we will have a detailed review of those results.

This technological superiority is increasingly a perishable commodity. We work hard to stretch our S&T funding by not only inventing the future, if you will, but also by speeding the introduction of new technologies to our warfighters. One way we are doing this is through applied technology councils and advanced technology demonstrations.

The councils, the applied technology councils, are composed of two and three star, senior level representatives from the Air Force Research Laboratory, our acquisition product centers, and our major user commands. Their focus is on assessing the quality, utility, and time phasing of our advanced technology demonstrators.

These councils are ensuring that up-front documented planning by all the stakeholders take place to improve the transition timeliness of demonstrated technologies from the laboratory to the customer. This new process ensures that the Air Force Research Lab pursues those ATDs with the highest user support and transition funding. We hold an Applied Technology Council meeting with each Combat Command every year and, thus far, have commissioned 22 Advanced Technology Demonstrators that have transition funding identified as a result of this process.

The quality of our program is assessed by the Air Force Scientific Advisory Board through yearly reviews. Twelve technical areas were recently identified as world class research during the last cycle of these reviews; let me highlight just a few of these if I could.

The Air Force has been the world leader in developing atmospheric compensation technologies that allow high energy laser beams to propagate through the atmosphere. We do this by first detecting the distortion the atmosphere causes to the laser beam, and then instantaneously adjusting away from the laser so that the beam reaches a target in a near perfect condition. I brought along some photographs of satellite imagery with and without atmospheric compensation that were taken from our research site at Kirkland Air Force Base, New Mexico, and they are on display here. [Indicating]

Our Space Weather Research at Hanscom Air Force Base, Massachusetts is another world class operation. Recently, Air Force scientists developed the first real time model of global electron density profiles, providing critical input for communications and global positioning systems. This model supplies information crucial to the design, operation, and simulation of a wide variety of communications, navigation, and surveillance systems.

On display is a mass model of the Compact Environment Anomaly Sensor, or CEAS. It was launched in the year 2000 and has mapped areas in space that are hazardous to onboard electronics.

Working closely with operational users, the AFRL researchers at Wright-Patterson Air Force Base, Ohio continue to develop and transition new filter technologies that provide improved eye protection for aircrews from various levels of laser threats. The Laser Eye Protection Program is enabling aircrews to conduct day and night air operations without visual jamming or personal injury.

You can see some of the products of this research in the form of the eye-glasses that are in the two cases here that we brought along. [Indicating]

In addition, I have also brought along a recent version of our Panoramic Night-Vision goggle. [Indicating] This device dramatically improves the field-of-view of both in the horizontal and the vertical to the user, thereby enhancing both mission utility and most importantly, aircrew safety.

There are many other technology areas that deserve special mention, but let me just highlight a few, if I could.

Senator ROBERTS. Keep going.

Dr. DANIEL. Yes, sir. Let me highlight just a few examples. One of these is our unmanned combat air vehicle, or UCAV, which is an area that is generating increased excitement.

Our current joint major development demonstration program with DARPA—this is a jointly funded program that is actually managed by DARPA with an Air Force colonel as a program manager—is now in its fourth year. Flight vehicle checkout and ground testing of the first demonstrator designated the X–45A is underway, with a projected first flight in September of this year. We also recently completed fabrication of the second X–45A.

I brought along a very small—it is nearly a 1/50th scale model maybe to help put this in perspective. The UCAV when you see the actual vehicle, it has a wing span that is about the same as an F–16 fighter. It is actually a sizeable vehicle.

Our S&T Program is also providing the technology base for micro satellites. It may offer new options in space applications such as satellite servicing, or launch on demand. Clusters, or formations of micro satellites cooperating to perform the job of current large satellites may ultimately allow space missions to be performed more cheaply and effectively with higher survivability and flexibility.

I brought along a 1/20th scale model of TechSat 21. [Indicating] This is a microsatellite that we will launch in a three-satellite formation in the year 2004. Hypersonics is yet another area of high interest to Air Force S&T. Our HyTech program achieved major successes in fiscal year 2001 with the ground test demonstration of a conventional jet-fueled scramjet, so-called hydrocarbon fueled scramjet, producing predicted levels of thrust over the Mach 4.5 to Mach 6.5 range. This research which you may have seen was recently featured on the cover of *Aviation Week*.

In addition, the Air Force is leading a DOD-directed activity to formulate a National Hypersonics S&T Plan which Dr. Etter also mentions in her written testimony.

I brought along a 1/3rd scale model of our HyTech ground engine demonstrator. It is the white engine that you can see just—perhaps can see just behind the X45. [Indicating]

In conclusion, let me say that the Air Force is fully committed to providing this Nation the advanced aerospace technologies required to meet America's national security interests around the world, and to ensure that we remain on the cutting edge of flexibility, performance, and affordability.

The technological advantage that we enjoy today is a legacy of decades of investment in S&T. Likewise, our future warfighting capabilities will be substantially determined by today's investment in S&T. I am confident that we can lead the discovery, development, and timely transition of affordable, integrated technologies to keep our Air Force the best in the world.

Mr. Chairman, thank you again for the opportunity to appear before you today, and thank you especially for your continuing support of Air Force Science and Technology.

Senator ROBERTS. All right.

[The prepared statement of Dr. Daniel follows:]

PREPARED STATEMENT BY DR. DONALD C. DANIEL

Mr. Chairman, Members of the subcommittee, and Staff, the United States Air Force is committed to a robust Science and Technology (S&T) Program that enables us to achieve our vision of an integrated air and space force capable of rapid and decisive global engagement. In 1944, General Hap Arnold, the "founding father" of the United States Air Force, stated, "The first essential of air power is pre-eminence in research." This was true in 1944 and it is still true today. By continuing our investment in a broad and balanced selection of technologies, the Air Force will retain its dominance of air and space in future conflicts.

Innovation is vital part of our aviation heritage and it is the key to ensuring the Air Force will meet the challenges of tomorrow. We must be prepared to counter the worldwide availability of advanced weapons, wide-ranging activities, increasing regional instabilities, and other emerging and less predictable threats. We are developing "leap ahead" technologies that permit flexible forces capable of operating far from home on short notice. We must also be able to afford these innovations once we develop them in order to transform the Air Force to fulfill our vision. To meet these challenges, we search out the most promising and affordable technologies in order to win decisively, protect our forces, and minimize collateral damage.

THE AIR FORCE S&T PROGRAM

The current Air Force S&T Program uses guidance from the National Military Strategy, Defense internal planning documents, Joint Staff guidance, and the Air Force Strategic Plan to focus our S&T investment. The resulting Air Force S&T Plan establishes a program that is balanced across our investments in Basic Research, Applied Research, and Advanced Technology Development, as well as across a diverse number of technology areas and the basic sciences. We balance our investment in long-range research yielding potential breakthrough technology with efforts to meet the more near-term needs of the operational warfighting commanders.

To ensure program relevance, we involve system developers and warfighters to focus our efforts on the warfighters' most urgent needs. Finally, to ensure the technical quality of the program, the Air Force Scientific Advisory Board, the Department of Defense Reliance Technology Area Review and Assessment teams, the Defense Science Board, and other peer groups regularly review, evaluate, and critique our S&T programs. We feel that the result is an S&T program of validated high quality and relevance.

S&T PLANNING PROCESS

In regards to our planning, I am pleased to be able to give you an update on our S&T planning review that we have undertaken in response to Section 252 of Public Law 106–398, the National Defense Authorization Act for Fiscal Year 2001. We have approached this review enthusiastically and have received overwhelming participation from, not only the Air Force S&T community, but the requirements, planning, logistics, and user communities as well. Currently, we have over 250 people involved in this review: approximately 140 from the S&T community; 60 from the requirements, plans, and logistics communities; and 50 from the user community.

As you required us to do, the S&T planning review will identify the short-term objectives and long-term challenges of the Air Force S&T Program. The review includes an assessment of the budgetary resources that are being used to address the short-term objectives and long-term challenges; the budgetary resources that are necessary to adequately address those objectives and challenges; and a course of action for each projected or ongoing Air Force S&T program that does not address either the short-term objective or the long-term challenge.

The review has been divided into three distinct phases of activity. Phase I focused on identifying the objectives and challenges. This work was largely accomplished in the January through April timeframe and was completed last week when the Air Force Council approved the objectives and challenges. Phase II concentrates on indepth investigations and analyses of the work that needs to be accomplished in order to meet the short-term objectives and long-term challenges. Integrated Product Teams and workshops have been formed to examine each short-term objective and long-term challenge, respectively. These results will also be briefed to the Air Force Corporate Structure and at the next Air Force S&T Summit in September. Phase III completes the review with an outbrief to the Secretary of the Air Force to enable the results to be communicated to the Secretary of Defense and the Comptroller General.

The Short-term Objectives that have been approved by Air Force leadership are: Target Location, Identification, and Tracking; Command, Control, Communications, Computers, and Intelligence; Precision Attack; Space Control; Access to Space; Aircraft Survivability and Countermeasures; Sustaining Aging Systems; and Air Expeditionary Force Support. The Long-term Challenges receiving similar approval are: Finding and Tracking; Command and Control; Controlled Effects; Sanctuary; Rapid Aerospace Response; and Effective Aerospace Persistence.

I am convinced that this effort will provide both a short-term, as well as a long-term focus to our S&T Program. The all-encompassing nature of the review has produced a set of objectives and challenges that reflect the enduring missions and capabilities that the Air Force provides to the Joint Force Commander. Further, they also draw from a broad range of technologies for their potential solution.

Also, contributing to my enthusiasm for the review is the fact that it is closely coupled to other key Air Force documents. For example, the short-term objectives and long-term challenges are closely linked to the Air Force Core Competencies and operational mission areas. Indeed the short-term objectives and long-term challenges related to Command and Control are directly linked to all six of the Air Force Core Competencies. Mastering the Core Competencies makes possible the achievement of Global Vigilance, Reach, and Power, the key elements of the Air Force Vision 2020. Thus the clear connectivity of the S&T objectives and challenges to the Air Force Core Competencies ensure that the Air Force S&T program is directly supporting the Air Force Vision. Results of this review will be used to update the Air Force S&T Plan, and they will also be an important input to the next update of the Air Force Strategic Plan.

Today, the execution of our S&T effort is the responsibility of the Air Force Research Laboratory (AFRL). Their mission it is to lead the discovery, development, and integration of affordable warfighting technologies for our aerospace forces. We are proud of AFRL, its people, programs, and facilities. It conducts a vigorous S&T Program in the following areas: basic research; propulsion; sensors; space vehicles; materials and manufacturing; human effectiveness; information; directed energy; air vehicles; and munitions. The S&T planning review effort that you have directed us to undertake will strengthen this Program as we move forward into what promises to be an exciting and challenging period for our Nation.

S&T BUDGET

The single most important factor to strengthening the Air Force S&T Program is an overall increase in the Air Force topline funding. We have been faced with the reality of a fiscally-constrained, but operationally-demanding environment. The high operations tempo the Air Force has sustained in support of peacekeeping operations and conflicts, such as Kosovo, has placed a great burden on our people and resources and strained our ability to maintain current readiness and make necessary future investments such as S&T.

In spite of these tight budgets, the Air Force is working hard to increase S&T funding and maintain a balanced S&T portfolio. In conjunction with this, there has been a significant increase in the involvement of the warfighting commands and senior Air Force leadership in S&T budgeting decisions. We have established twice yearly S&T Summits where the Secretary of the Air Force, the Air Force Chief of Staff, and the Air Force four-stars review the S&T portfolio and new initiatives. The first two reviews resulted in increased emphasis for research on sensors and information technology to advance our ability to find and attack Targets-Under-Trees; for accelerated materials development for improved Laser Eye Protection devices; for accelerating development of the Joint Battlespace Infosphere; and for completing important beam control demonstrations for our Directed Energy program.

MAXIMIZING OUR S&T DOLLARS

We will continue to leverage technology to achieve new levels of combat effectiveness. Our strategy is to pursue integrated technology solutions that support our warfighter's highest priority needs. We must also pursue the fundamental enabling technologies that will improve tomorrow's Air Force. As technological superiority is increasingly a perishable commodity, we work hard to stretch our S&T funding, by not only "inventing the future" ourselves, but also by speeding the introduction of new technologies to our warfighters.

One way we are doing this is through our Applied Technology Councils and the Advanced Technology Demonstrations (ATDs). The councils are composed of two- and three-star, senior-level representatives of the AFRL, our acquisition product centers, and our major user commands. Their focus is on assessing the quality, utility, and time-phasing of our ATDs. These councils are ensuring that up-front, documented planning by all stakeholders takes place to improve the probability that a demonstrated technology will transition out of the laboratory to the customer. This new process will ensure AFRL pursues those ATDs with the highest user support and transition funding. We hold an Applied Technology Council meeting with each Combat Command every year, and have commissioned 22 ATDs that have transition funding in the fiscal year 2002 budget, and 30 potential ATDs that we are still working to fund in outyear budgets. The Applied Technology Council process has significantly contributed to focusing the S&T Program on warfighter needs by bringing direct operational input into development of a responsive and relevant demonstration program.

Since deployed technology may remain in use for decades, the Air Force S&T Program not only focuses on enhancing performance, but we have also increased our emphasis on the reliability, maintainability, and affordability of weapon systems. Emphasizing affordability from the very beginning through training of our management and engineering staff, as well as through careful review of technology transition pilot projects, increase our potential to reduce the costs of technology early in the process and throughout a product's life cycle.

We are very selective about investing in the appropriate technological opportunities. We constantly seek opportunities to integrate planning by the Air Force and leverage our S&T funds by cooperating with other Services, Agencies, the private sector, and international partners. For example, we rely on the Army as the lead Service for chemical-biological technology research. The Air Force also has strong inter-Agency efforts such as our program in aging aircraft, which is focused on detection and amelioration of corrosion and fatigue in aging structures. It is closely coordinated with the civilian aging-aircraft research programs at the National Aeronautics and Space Administration and Federal Aviation Administration. Finally, the Air Force is closely involved in international technology cooperative efforts for S&T such as the cooperative technology development programs with France, Germany, and the United Kingdom in tactical missile propellants, insensitive high explosives, and aircraft battle damage repair. Another example of international cooperation is the bi-lateral work we are doing with the United Kingdom on developing a novel new target detection device, fuze, and warhead integration concept.

International cooperative efforts help us increase the number of sources for innovative ideas and transition new capabilities to the warfighter. A key example is our extensive involvement with the NATO Research and Technology Organization, which oversees all of the cooperative military research the nineteen NATO members and the Partnership for Peace nations wish to share with each other. I sit on governing board of this group along with Dr. Etter, who is the senior U.S. representative, and Mr. Dan Mulville from NASA. At the next level are seven major technical panels each of which include three U.S. senior scientists and engineers. Finally, we have close to a hundred of our folks participating at the technical team level. This cooperation in the early stages of technology development also helps to ensure any ensuing technology product will be interoperable with the equipment of potential allies in coalition operations.

WORLD CLASS RESEARCH

The quality of our program is assessed by the Air Force Scientific Advisory Board (SAB) through yearly reviews. The SAB conducts an in-depth review of half of the S&T Program each year, covering the entire program over a 2-year period. Twelve technical areas have been identified as world class research during the last cycle of reviews—let me highlight a few of these areas that were identified as world class.

The Air Force has been the world leader in developing atmospheric compensation technologies to allow high power laser beams to propagate through the atmosphere. It does this by detecting the distortion the atmosphere causes to the laser beam and then instantaneously adjusting the wavefront of the laser beam so that when the beam reaches a target it is close to perfect. This is an enabling technology for the Airborne Laser program, as well as future ground-based lasers. Since the technology applies to any laser beam, it also enables ground-based space imaging systems to have resolution comparable to that of space systems. In fact this technology is now the baseline for large astronomical telescope systems. Some photographs of satellite imagery with and without atmospheric compensation that were taken from our research site at Kirtland Air Force Base, New Mexico, are on display here.

Another SAB-rated world class research area is our Information Directorate Ground Moving Target Indicator and Sensor Fusion Laboratory at Rome, New York. This unique laboratory develops, evaluates, and transitions advanced trackers, information exploitation tools, dissemination technology, multi-intelligence fusion exploitation, and advanced fusion architectures. An example of one of the lab's successful technology transitions is the Moving Target Information Exploitation system, an all-source, web-enabled information architecture. The Moving Target Information Exploitation system processes, catalogs, exploits, and disseminates information to web-based users utilizing real-time tools allowing relatively low-cost distribution of tailored Moving Target Information data. It has been demonstrated during several large-scale experiments, and has also been transitioned to two Initial Operational Capability locations at Warner Robins Air Force Base, Georgia, and Langley Air Force Base, Virginia.

Our research in Automatic Target Recognition at Wright-Patterson Air Force Base, Ohio will allow future weapon systems to automatically identify and target specific ground targets. We are actively working to transition this technology via an Advanced Technology Demonstration, entitled Air-to-Ground Radar Imaging, and we are developing technologies with payoffs well beyond automatic target recognition, in areas ranging from combat search and rescue to drug interdiction operations.

The Space Weather research at Hanscom Air Force Base, Massachusetts, is another world class operation. Here, we have a robust modeling capability including empirical and theoretical models that specify and forecast space weather from the Sun to the ionosphere. Recently, Air Force scientists developed the first real-time model of global electron density profiles, providing critical input for communications and global positioning systems. This model supplies information crucial to the design, operation, and simulation of a wide variety of communications, navigation, and surveillance systems. Environmental effects forecasted by this model range from intermittent outages caused by ionospheric scintillation to satellite system failures caused by intense fluxes of magnetospheric particles. The researchers at Hanscom also have developed hardware to protect our valuable space assets. This is a mass model of the Compact Environmental Anomaly Sensor that was first launched in 2000 and has mapped areas in space that are hazardous to onboard electronics.

Working closely with operational users, AFRL researchers at Wright-Patterson Air Force Base, Ohio continue to develop and transition new filter technologies that provide improved eye protection for aircrews from varied levels of laser threats. The Laser Eye Protection program is enabling aircrews to conduct day and night air operations without visual jamming or personal injury. You can see some of the products of this research in the form of eye-glasses here. In addition, I have brought along a recent version of a Panoramic Night-Vision Goggle that dramatically improves the field-of-view of the user thereby enhancing their mission utility and safety of use.

NOBEL PRIZE WINNERS

The Air Force through its Basic Research Program sponsors a broad spectrum of topics at many universities throughout the United States. Approximately 60 percent of the $200+ million Air Force Basic Research program is allocated to universities through our grant process. These university investments have been highly successful for the Air Force and the entire United States. The Air Force Office of Scientific Research sponsors the work of exceptional people who provide basic research—-the fundamental core component of Air Force Science and Technology. An indication of the Air Force's ability to select truly world class researchers is that we identified and sponsored the research of 38 Nobel Prize winners years before they won, including the work of four Nobel Laureates in 2000: Professor Alan J. Heeger of the University of California, Santa Barbara, who won a Nobel Prize in Chemistry; Professor Herbert Kroemer of the University of California, Santa Barbara, who won a Nobel Prize in Physics; Professor Paul Greengard of the Rockefeller University who won a Nobel Prize in Medicine; and Dr. Jack Kilby of Texas Instruments who also won a Nobel Prize in Physics.

EXPEDITIONARY AEROSPACE FORCE

The operations in Kosovo have served as a proving ground for many of the technologies developed by the Air Force S&T Program, especially in the area of information operations. We validated the reach-back concept, pulling forward information from continental United States-based support elements to enhance the effectiveness of our deployed fighting forces, while reducing the footprint of our combat support forces. The Air Force tested high-tech products such as Broadsword Secure Intelligence Gateway which allows intelligence analysts to access any U.S. intelligence database and the capability to make a single picture from multiple Predator images. And, for the first time, we tied key mission processes to web-based networks, making critical information instantly available to in-theater forces.

The Air Force is applying lessons learned in Kosovo to its EAF planning. We're developing and incorporating new technologies and concepts to ensure our warfighters get the right information, at the right time. To do that, "network-centric" information infrastructures will use "smart push" to make assured information available to the warfighters, while providing ensured and easy access, or "pull," of timely assured information in a user-friendly format. Our theater deployable communications systems will provide our aerospace expeditionary wings with secure and nonsecure voice, data, imagery, e-mail, and messaging—doubling the current capability of our aerospace expeditionary wings, while getting to the fight with only one-half the current airlift requirement for the same mission.

Using the latest advances in information technology developed by the Air Force Research Laboratory (AFRL), we have demonstrated several advanced planning and execution tools in our Joint Expeditionary Force Experiment. The Joint Assistant for Deployment and Execution allowed us to generate time-phased force deployment plans and tasking orders to send any combination of forces anywhere in the world, and have them arrive in the right place at the right time, and in the right sequence. This tool will allow the Air Force to complete in 1 hour a process that normally takes 2 weeks. Using a unique adaptation of the Global Air Traffic Management system, we were able to use both military and civilian air-traffic communication systems to provide continuous contact with our airlifters. Still another tool we demonstrated was the Worldwide Aeronautical Route Planner. Using multiple parameters, such as flight performance models, global weather patterns, country avoids, current navigational aids, and airway restrictions, this tool plots the most fuel and time efficient route possible in seconds versus hours.

Training is another integral part of implementing our EAF vision. The technology for Distributed Mission Training is an area that holds great promise. Using state-of-the-art simulation technology, Distributed Mission Training permits geographically-separated aircrews to jointly train in a synthetic battlespace, connected electronically from their distant air bases. Importantly, Distributed Mission Training delivers this enhanced training from the home station, which helps the Air Force limit the amount of time airmen spend deployed and facilitates the training of Air Expeditionary Forces as they prepare for deployment.

THE LEADING EDGE

There are many other Air Force technology areas that deserve special mention, but I will limit my testimony by describing just a few examples. Unmanned Combat Air Vehicles (UCAV) is an area that is seeing increasing support. The current joint major technology demonstration program with the Defense Advanced Research Projects Agency has entered its fourth year. Flight vehicle checkout and ground testing of the first demonstrator designated the X–45A is underway, with projected first flight in September of this year. The second demonstrator fabrication is complete and it was recently airlifted to the National Aeronautics and Space Administration Dryden Flight Research Center from Boeing, St. Louis, Missouri. Over 25 of the 90 demonstrations scheduled for Phase II have been accomplished. We expect completion of Phase II by the fall of 2003.

The joint DARPA/Air Force UCAV program may well serve as a model for technology transition through detailed technology identification and maturation. Phase I of the program involved operational comparative analysis studies to assess the benefits of a UCAV system and identify the technologies, processes, and system attributes necessary for such a system to achieve those benefits. This initial phase was completed in fiscal year 1999. Phase II is the maturation and demonstration of these technologies, processes, and system attributes through the fabrication and demonstration of the two demonstrator vehicles and their support systems. This second phase will provide initial risk reduction activities and multi-vehicle simulation and flight demonstrations. Phase II will conclude with end-to-end demonstrations, validating the technical feasibility of a UCAV performing a Suppression of Enemy Air Defenses (SEAD) mission. A 1/48 scale model of the UCAV is on display.

To increase aircraft survivability and operational efficiencies, the Air Force is developing both manned (F–22 and Joint Strike Fighter) and unmanned (UCAV) flight vehicles that can carry and employ weapons from both external and internal weapons bays. To increase the number of weapons the flight vehicle can fit into their internal weapons bays, part of our investment strategy focuses S&T funding on developing and demonstrating smaller precision weapons.

One of the small munitions currently being flight demonstrated is the Small Smart Bomb. The program is divided into three phases. Phase I of the program, completed in 1997, demonstrated a six foot long, six-inch diameter, 250-pound, adverse weather, low-cost, guided weapon capable of penetrating six feet of reinforced concrete. The small guided bomb reduces the logistic footprint over existing bombs and increases multiple kills per sortie. The model shown here, Small Smart Bomb with Range Extension, builds on the success of the first phase. The Phase I Small Smart Bomb was outfitted with a fold-out wing and control tail surface kit, that expands the footprint of the munition to a 35 nautical mile downrange by 20 nautical mile off-boresight range while maintaining its six foot reinforced concrete penetration capability. The expanded footprint will simplify mission planning by allowing a single release point for multiple munitions. Phase III of the program will build upon the success of the Phase II by integrating a low-cost, laser radar seeker with automated target recognition algorithms to the small smart bomb. This program has an accuracy goal of 1.5 meters. The increase in munitions accuracy and the decreased volume of explosive will reduce the collateral damage that can occur with larger munitions..

Advances in technologies for power, electronics, micro-electro-mechanical systems, structures, and payloads are also enabling significant reductions in the size, weight, and cost of satellites. Our S&T Program will provide the technology base for 10–100 kilogram microsatellites that will offer new options in many areas of space applications. Applications previously considered not cost-effective due to size and weight limitations, such as satellite servicing or launch on demand, become possible. Clusters of formations of microsatellites cooperating to perform the job of current large satellites may ultimately allow space missions to be performed more cheaply and effectively, with higher survivability and flexibility. Here is a model of TechSat 21, a three satellite formation scheduled for launch in 2004. Here is a thin film photovoltaic array and the current technology it replaces. This array will be incorporated into the TechSat 21.

To further the miniaturization of space platforms, DARPA and the Air Force have funded ten universities to explore the military utility of innovative, low-cost nanosatellites. These nanosatellites, weighing two to ten kilograms, will perform such experiments as formation flying algorithms, differential Global Positioning System navigation, miniaturized sensors, and micropropulsion.

On July 19, 2000, the Air Force launched MightySat II.1 into orbit. At 266 pounds, MightySat II.1 is one of the most sophisticated satellites of its size ever launched. At a total S&T investment of about $40 million, this small satellite provides researchers with a "lab bench" to test emerging high-payoff technologies for space. MightySat II.1's primary payload is a Fourier Transform Hyperspectral Imager, currently the only Department of Defense (DOD) demonstrator for hyperspectral surveillance technology in orbit. Over one hundred images have been taken to date. This summer, we will launch the Warfighter–1 hyperspectral sensor on board OrbView–4, OrbImage's commercial remote sensing satellite. Warfighter–1 will allow us to continue our assessment of the utility of hyperspectral technology to perform military missions, such as detecting difficult military targets and categorizing types of terrain.

The Air Force is also conducting the Experimental Satellite System series to demonstrate increasing levels of microsatellite technology maturity. XSS–10, the first in the series, is scheduled to launch in March 2002. It will demonstrate semi-autonomous operations and visual inspection in close proximity of an object in space—in this case a Delta II upper stage. In fiscal year 2004, we will launch XSS–11, which will demonstrate autonomous operations and provide experience with command and control in proximity operations to another space object.

Hypersonics is another area of high interest to Air Force S&T. The Air Force HyTech program achieved major successes in fiscal year 2001. The first-ever demonstration of a conventional jet-fueled scramjet producing predicted levels of positive thrust over the Mach 4.5 to Mach 6.5 flight range was accomplished. The engine was developed by Pratt & Whitney in collaboration with AFRL engineers, and this research was recently featured on the 26 March 2001 cover of *Aviation Week*. In addition, the Air Force is leading a DOD directed activity to formulate a National Hypersonics S&T Plan which has been discussed by Dr. Etter. I've brought along a 1/3 scale model of the HyTech ground engine demonstrator.

While hypersonics is at the forefront of revolutionary propulsion technology, we are continuing the development of evolutionary turbine engines. The Integrated High Performance Turbine Engine Technology (IHPTET) program is a national effort between DOD, NASA, and industry to double turbine engine thrust to weight by fiscal year 2003 baselined on that available in 1987. The Air Force is the DOD lead for this program. The program is highly leveraged with industry contributing approximately 50 percent of the cost. IHPTET has ambitious, rigorous goals with objectives, technical challenges, and approaches identified to meet these goals. For example, turbine blades using a double wall, "supercooling" concept enables the Joint Strike Fighter's required turbine life; and advanced intermetallic refractory alloys for turbine blade design enables engine operation at high temperature to double turbine blade life to 4,000 hours. IHPTET technologies provide potential excellent return-on-investment with a 20–40 percent fuel efficiency improvement.

THANKS TO CONGRESS

I want to thank you for the strong congressional support for Air Force S&T. Our S&T appropriations for the past 2 years have averaged over $275 million above our requested amount and we greatly appreciate your interest in this important program. Your support has benefited several key technologies in the areas of space and sensors.

For example, these additional funds are allowing us to better protect our Nation's space assets from both natural and man-made threats. We are furthering our fundamental understanding of ionospheric processes and improving our ability to forecast space weather phenomena. Later this year, we will launch an instrument to demonstrate the ability to detect and locate radio frequency threats to our satellites. Finally, you are helping us make strides in the important task of decreasing the cost of spacelift by reducing the cost to produce lighter weight launch vehicle shrouds, while improving their structural performance.

Last year, you also supported upgrades to the Integrated Demonstrations and Applications Laboratory at AFRL. These funds are being used to acquire and install a multispectral synthetic battlespace simulation capability that will allow simulations at dramatically reduced cost. In addition to reducing research costs, this capability provides an affordable means to evolve the 21st century air and space sensor technologies required for next generation "system of systems" concepts. These concepts will utilize multiple sensors on both airborne platforms and space assets to successfully accomplish combat missions.

CONCLUSION

The Air Force is in the midst of a technological and organizational transformation that is radically changing aerospace contributions to the nature of war. Stealth and precision strike, in particular, have injected "leap ahead" improvements into combat power unlike any we have known since the introduction of the jet engine. We are making important strides in command and control, long-range power projection, and mobility in support of an integrated Expeditionary Aerospace Force.

The Air Force is fully committed to providing this Nation the advanced aerospace tools and technologies required to meet America's interests around the world and ensure we remain on the cutting edge of technology, performance, military flexibility, and affordability. The technological advantage we enjoy today is a legacy of decades of investment in S&T. Likewise, our future warfighting capabilities will be substantially determined by today's investment in S&T. As we face the new Millennium, our challenge is to advance technologies for an Expeditionary Aerospace Force as we continue to move aggressively into the realm of space technologies. I am confident that we can lead the discovery, development, and timely transition of affordable, integrated technologies that keep our Air Force the best in the world. As an integral part of the Department of Defense's S&T team, we look forward to working with Congress to ensure a strong Air Force S&T Program tailored to achieve our vision of an integrated air and space force.

Senator ROBERTS. Admiral, we are going to recognize you. I am not too sure if we can get all of those demonstration projects, but can we—okay, we are getting ready here, I can see.

What is it down there that you think that Senator Santorum and I and appropriate staff ought to take a close look at?

Dr. DANIEL. Sir, if you have not seen—I assume you are talking to me?

Senator ROBERTS. Yes.

Dr. DANIEL. Sir, if you have not seen the X45, it is to me a very fascinating vehicle, although this is a very small scale model.

Senator ROBERTS. Bring up the X45.

Dr. DANIEL. Again, that is about a 1/50th scale, and the actual vehicle is about the size of an F–16. This vehicle features two internal bomb bays; all the carriage of weapons will be internal. It has about a 3,000 pound internal weapons carriage capability.

It also has hard points on the wings where we can put fuel tanks should we choose to extend the range or ferry the vehicle, although typically the vehicle would be delivered in a C–17. We stack several of these in crates on a C–17, and that is part of the program, as well. Again, we are projecting first flight now for September.

Another one that you may want to take a look at are the laser eye protection devices. At first glance, these look like regular eye glasses. They will, in fact, shield aviators and aircrews from certain wavelengths of lasers. They are not particularly heavy. They are not particularly cumbersome, but they are very effective in shielding aircrews from certain wavelengths of lasers.

Sir, one of the things we want to do with these particular spectacles is over time, have a very broad range over which they will shield.

Senator ROBERTS. My goodness, look at that. [Laughter.]

Dr. DANIEL. We really need a picture of this. [Laughter.]

Senator ROBERTS. All right.

Dr. DANIEL. Of course, one of the technology challenges here is to——

Senator ROBERTS. Ride on, Dr. Daniel. [Laughter.]

Dr. DANIEL. I am going to put that picture on my wall, sir. [Laughter.]

Sir, one of the challenges is not only to shield the eyes from what is coming in——

Senator ROBERTS. You take the picture and I will put you on the wall, I will tell you that. [Laughter.]

Dr. DANIEL. But you still need to be able to see. The human still needs to be able to see. And, of course, there is that balance.

I think also if we could just maybe look at one more. TechSat 21 is a program that—this is the model here. [Indicating] That is about a 1/20th scale model. These satellites will go into orbit, actually collapse down into something that looks like a can. They deploy, and once they are in orbit into the elongated shape that you see now.

All along the sides of those are the panels that allow us to collect solar energy that, in fact, creates power for the satellite. This is quite an advance that we have made in materials technology. That is very, very thin material that allows us to do the solar collection and subsequent power generation.

Again, our plan right now is we will put three of these on orbit out of the same package. They will all be collapsed down, one sitting on top of the other. They will go into orbit, and this will be our first real experiment of formation flying, if you will, with microsatellites. We are projecting to do that about the year 2004.

Senator ROBERTS. All right. Admiral, knock our socks off.

STATEMENT OF REAR ADM. JAY M. COHEN, USN, CHIEF OF NAVAL RESEARCH; ACCOMPANIED BY BRIG. GEN. BILL CATTO, USMC, VICE CHIEF OF NAVAL RESEARCH

Admiral COHEN. Good afternoon, sir. I must tell you that I have heard of the singing Senators, but this is my first exposure to the Blues Brothers. [Laughter.]

So, it is good to know that you are laser protected. [Laughter.]

It is a great personal honor for me to be here representing the Department of the Navy. Mr. Chairman, the Department of the Navy includes both the Navy and the Marine Corps, and I am quite honored to have in support here, my Vice Chief of Naval Research, Brig. Gen. Bill Catto.

As you are aware, I previously submitted a written statement, so I will make some short comments surrounded here by the Marines.

I regret that Dr. Etter is not here. I am, unlike my counterparts on this panel, I am just a fleet sailor. She and they took me under their wing over the last year and have tried to mentor me, a very difficult task, in the area of Science and Technology. But I certainly second your comments on Dr. Etter, especially her personal dedication to reinvigorating the Science and Technology workforce.

Mr. Chairman, after I was on the job just a few months, we had the heinous attack on the U.S.S. *Cole* in October of last year. Several days later I received the following email which I would like to read to you. It is a fairly short email.

It says, "Dear Sir, My name"—and I will not include the last name or some details just to protect the individual. "My name is John, my nickname is Jake. I am 9 years old, and I live in North Carolina with my parents and sister. My dad is a First Sergeant who has been on many ships. When I saw the U.S.S. *Cole* on TV, I thought it was really bad. I have an idea that you could probably try with your ships that you build. You can put one more layer of steel on the ship, but it has to have air in between it because if a layer is blown up, there is still one more layer that can still keep it floating. Less people will probably die or injured. I came up with this idea when I heard about the U.S.S. *Cole* that had a hole in the ship. I hope you will try this just to see if it works. Sincerely, Jake."

Well, I must tell you there are a couple of things that keep me awake at night. One is the fear of technological surprise, and that has been addressed previously during this hearing. But the other was this email. This is a little bit like the letter that was written 100 years ago to the editor of the Richmond Dispatch asking if there was a Santa Claus. Of course, you are familiar with the answer, "Yes, Virginia, there is a Santa Claus."

It took me 2 months to answer this email, and the initial answer of course was, "Jake, you are absolutely right, but we do not build double hull ships because of cost and weight considerations."

When you think about how cheap steel is and how dear flesh is, that was not an email that I was going to write back to this 9-year-old whose father regularly deploys on Navy ships. I was able to send him back an email 2 months later thanking him for giving me the insight to see what we could do significantly to improve force protection.

And, Mr. Chairman, with your permission, I would like to hold up a card here. [Indicating] Perhaps, Tim, if you would just take it closer to the Chairman. With those laser glasses, he might have trouble seeing some of this.

Now this is just an artist's conception, Mr. Chairman, but what you can see there is, number one, a small UAV flying. As I said, we are a blue/green team in the Department of the Navy, and we are able to leverage very quickly the work that the Marines have done on Dragon Eye.

Major, if you will share with the Chairman what Dragon Eye is, and perhaps General Catto will help me here.

MAJOR. Senator, Dragon Eye is a man portable UAV. It weighs 4½ pounds. It has a day and night camera. The ground control station weighs under 10 pounds. It will fly for 10 kilometers, and it is something that will give a marine or a sailor a real-time tactical reconnaissance to help him see what is on the other side of the hill or in the fort. [Indicating]

Admiral COHEN. Now, Mr. Chairman, this will, as you can see just clip apart. It is very rugged. We designed it for a couple of flights. The other prototypes have gone through several dozen flights. We do not catch them when they land. They just go ahead and strike the earth. You can see they have electric props, and the wings fold.

The way it is launched is a sailor or a marine literally just throws it like you would a paper airplane, and it is electric driven.

This was conceived, and built, and delivered by the Naval Research Lab right down here on the Potomac, but it was in response to the Marines' desire for a private to be able to look over the next hill without sticking his head up and getting it shot off.

Fifth Fleet, which is right now under raised security conditions, asked for us to rapidly construct these and pass them to them, and with the Marines' help, we are doing that. They are sacrificing their initial lot to go and help. The view here is to give the COs of those ships the tactical awareness, situational awareness so, day or night, they can fly over a port that they might enter, or a contact of interest to them, and determine what the threat they think is to them.

Senator ROBERTS. It is still pretty heavy. Watch out. [Laughter.]

Admiral COHEN. Four and a half pounds, and we make these for about $10,000 a copy, and we view them as basically disposable.

Senator ROBERTS. Now this is available to the fleet now?

Admiral COHEN. Yes, sir. We are pushing them within the next month. Fifth Fleet will get between three and five with Marines to train the sailors who will throw them off the helo-deck, the stern, before a ship looks to enter port so the CO can surveil the harbor.

If he should see a wooden dowel with Saddam Hussein's face painted perhaps on the top of the dowel, giving an inappropriate symbol, maybe we want to be at an even greater level of defense. We are going to talk about some of the options we have.

So, Tim, if you could hold that up again. [Indicating]

The next thing that you see there, it looks like a Venetian blind hanging off the side. I am pleased that Senator Santorum was able to rejoin us because thanks to ARL Penn State, we have something, and we will get this to you. This is called LASCOR. You will see it is very, very thin. It is something we have used in Navy ships for some time, especially high up.

Senators, you could stand on that. It is just like corrugated cardboard. I mean, that is where we got the idea from. It is very thin steel, used as laser welding. If you fill that with the appropriate light substance, the Marines have made shelters for their Harriers and a 155-millimeter shell will not penetrate it.

Our goal would be to have this as a Venetian blind. Obviously, we could design the ships from this, but that is what I call the next step. The now step is to make this available as a Venetian blind, kick it off the gunnels prior to entering port, or in the event that you are threatened by swarm tactics, have it magnetic on the back side so that an explosion like the *Cole* kind of explosion, might cause gross deformation, but would not allow penetration of the ship's skin.

You see a diagram on there, and I might say below the DDG, you see a nuclear submarine. We are going to make these in saddlebag form, also, so that when they are in a tight area such as a canal transit or restricted waters, they will have the ability to put those on top side, above the water line, to defend against shoulder-fired weapons which might otherwise have an opportunity to penetrate.

In the Navy we have a big problem. In the Marine Corps, everyone is a shooter and they are very proud of that. In the Navy, we have a slightly different ethos. It is the Commanding Officer or the pilot who fights the ship. Everyone else is there to support. We say, take information into knowledge, finally into the wisdom necessary to release the weapon against the target.

The Marines, because of their new missions, whether it is peacekeeping, Somalia, or in an urban environment, have extrapolated what the police forces in America have used for so long. They call it the Command Decision Range, and this is where they use roleplaying to see—they show you a shadow, "Is this person holding a baby, or are they holding a new advanced weapon?" and then see how the Marine reacts, and they are able to grade and see if the Marine has the right attitude in terms of force protection, self defense, et cetera.

Well, on a ship in the morning, one of our young men or women might be mess cooking, okay, or chipping and painting. In the afternoon, we expect them to strap on a 45-caliber pistol or a 9-millimeter pistol, or an M–16 and defend the ship. Well, that is a significant transition to make.

So again, with the help of the Marines, we have gone ahead and in Naval environments taken these command decision, CDS, made them, passed them to all the number fleets—and as a research man, I do not tell the ship COs what level they should be at, but we have given them three different levels for the terrorist threat. Now the numbered fleet commanders can tell the ships to use these for training.

I want to show you one other thing on here. We always have an issue in rules of engagement of what we call the tourist versus the terrorist. Being Americans, we do not think a lot about shooting first. We are ready to take a lot of injury ourselves.

Well, again, the Marines working with us through Naval Research, have developed—and you have read about it in the open press—a high powered microwave which if you become exposed to it, makes your skin feel like it is on fire. Now, it does no permanent damage as long as you turn around and walk away.

Well, how do you warn people? What we were looking at is just using geometry, and we are going to have a green light over yellow light over red light scenario. I am actually making one of these. They will be hatch shippable on the submarine as our first example. They will have a 360-degree range of this high powered microwave.

Now if you are a tourist in your Boston Whaler and you are approaching one of our ships, and you start to get warm—first, you see green, and then you see yellow. When you see red, you are getting warm. You are probably going to turn around.

But if you are a terrorist and you believe that you are prepared to sacrifice your life, you will forge on. At that point, our young sailors who might have been mess cooking in the morning, if the rules of engagement are as such that they are protecting their ship, will engage that enemy. So we are excited about this. These things are actually happening today, and you can see the advantage of the blue/green partnership.

Senator ROBERTS. But in relation to the U.S.S. *Cole,* even if you were in threat condition Delta, there was no—how can I phrase this? Use of deadly force is not—it is not in the rules of engagement. In other words, you are going to have to have a perimeter. You are going to have to have a situation to identify the terrorist—

as recorded at least in the Intelligence and Armed Services Committee hearings, indicated that the sailor looked right down at the boat. There was nothing really visible. It was just two individuals who were waving and smiling. It was completely open, but obviously, all of the explosives were below the water level.

You are going to have to have a perimeter. I can see this could be extremely helpful in regards to that. You establish the perimeter depending on where you are, and then you are saying that you have—when that red turns on, and it gets uncomfortably hot, that if they say, "All right, full speed ahead," what happens then?

Admiral COHEN. Well, first of all, they are still experiencing this tingling sensation.

Senator ROBERTS. Right.

Admiral COHEN. At that point, because we have marked that, basically, we have given fair warning. Now, these are just my ideas and research. I am not a fleet commander, and I do not establish what the threat con levels are or when deadly force will be utilized, but I am trying to give aids to the commanding officer so he or she has situational awareness, and that the young people who are forced to make those kinds of decisions on short notice, at least——

Senator ROBERTS. Well, the Israeli Navy had a very interesting concept. They establish a perimeter, which is the whole bay area, and they use depth charges on a very regular basis. Now, that does tend to encourage people not to go there.

Admiral COHEN. Yes, sir. [Laughter.]

Senator ROBERTS. I am just trying to say that with regards to perimeter, more especially in a port like Aden where we went in, what, 27 straight times and because of that, got very used to it, but then if you really took a look at it, some of the red flags came down in our collection efforts, the analysis, left a great deal to be desired in my personal opinion.

But you are going to have to come up with the technology to allow that ship commander to have a perimeter, and then turn on that red light. Then what do you do? That was my next question, and you just went into that a little bit.

Admiral COHEN. Well, I laughed a little bit, sir, because shortly after the incident with the U.S.S. *Cole* happened, I went to the Israelis and other navies and I asked them how they handle situations like this. The Israelis told me they would be unable to help me because of the exact situation you said. They establish a perimeter. Anybody who violates that perimeter as far as they are concerned is authorized to be killed. Now that has not traditionally, in a peacetime environment, been the United States' Navy approach.

Senator ROBERTS. No, that is not feasible.

Admiral COHEN. What I am showing here is the "Defense in Depth" where we have shown you the LASCOR so that in the event this person does get through, I have a final defense, and that is deformation of the hull, but not penetration. So our most valuable asset——

Senator ROBERTS. That would be the net that came down.

Admiral COHEN. Exactly, sir.

Senator ROBERTS. I see.

Admiral COHEN. Exactly.

Senator ROBERTS. OK. So he keeps coming and the red light is on, you deploy the net, and then you use—well, if he keeps coming obviously toward that net, I would assume under rules of engagement in certain situations, you could use deadly force.

Admiral COHEN. Yes, sir, and I think Navy regulations tend to favor the commanding officer, we favor the bold.

Senator ROBERTS. But you have also had this—what did you call it? [Indicating] What is this called? [Indicating]

Admiral COHEN. It is called Dragon Eye.

Senator ROBERTS. OK. Dragon Eye. So the CO has had an opportunity to have a pretty good overlook of the area, but of course, with the terrorists, why, that is not what they are going to do.

Admiral COHEN. In a classified format, I will talk to you separately.

Senator ROBERTS. Certainly.

Admiral COHEN. We can tell you some of the enhancements.

Senator ROBERTS. We have called up in that regard.

Admiral COHEN. I have given you the layman's view, but I think people can understand that there are other enhancements.

Senator ROBERTS. Well, we have a lot of lessons-learned hearings in regards to U.S.S. *Cole* and force protection, and we will even come back up. I am sorry to interrupt. Go ahead.

Admiral COHEN. No, not at all, sir.

The final thing, if you look at this picture just up on your left, it really looks confusing. [Indicating] Now, what you are seeing there is the projection from the 360-degree camera. That is what is on the tripod.

Thanks to computers, we are able to know what the geometry of that hemisphere is, and we can take that picture, and although it is not the same picture, you can see on the very next computer monitor, we took a very similar picture on one of our yard patrol crafts. It is my enable research flag ship. We just took it up to New York City and had thousands of people come on board. We had about three dozen kiosks to show them what we were doing in naval research.

We had this camera. This is leveraged off what the Army has done. They call it Silent Sentinel, where they are able to recognize human forms walking in a forest. But we can take that very abstract picture, reduce it, thanks to computers, to a panorama.

We are looking now to make this—you may have read about it in the paper—a 360-degree periscope that would go on top of our normal periscope which has a very limited field of view, not only in daylight, but also in infrared, and use these programs that the Army and others have developed for shape recognition, shape motion, et cetera, as an alertment for our COs if they operate in highly populated waters. Regrettably, the oceans are getting more crowded every day.

Now, Mr. Chairman, there is a lot more I could say, and I will look forward to your questions, but with deference to Dr. Alexander, I will conclude my comments.

Senator ROBERTS. OK.

[The prepared statement of Admiral Cohen follows:]

PREPARED STATEMENT BY REAR ADM. JAY COHEN

Mr. Chairman, distinguished members of the subcommittee, thank you for this opportunity to discuss the Department of the Navy's Science and Technology Program.

When Admiral Clark assumed the watch from Admiral Jay Johnson last summer, he said that our people were our first priority. His Marine Corps counterpart, General Jones, is equally committed to doing everything we can for his few and proud Marines.

One of the most important ways we can keep our people and recruit more like them is to give them the best working conditions possible. While the bedrock of our Navy and Marine Corps is good leadership, technology is the foundation that rests on that bedrock. Admiral Clark has directed me, as Chief of Naval Research, to make science and technology work for our people in the Fleet. Since I also wear the hat of Assistant Deputy Commandant (Science and Technology) for the Marine Corps, I answer to the same marching orders from General Jones—make science and technology work for the Marine. So I will couch quite a bit of my testimony today in terms of what we're doing to deliver capabilities for sailors and marines. I think we have a great record, a sound process, and a terrific future.

As Chief of Naval Research, I want to protect our warfighters from technological surprises, while giving them the tools to inflict surprises on our adversaries. The business of surprise is especially important today. The threats we face are too variable to yield to the clear responses available during the Cold War. I would like to draw out one fundamental lesson from the Cold War and other more recent situations—as uncertainty increases, options increase in value. My technical priorities electric warship, missile defense/space, human factors, environment, and efficiency—will offer "out of the box" capability options; it's my job to give the Secretary, and the CNO, and the Commandant, technology options they can exercise at need.

Our science and technology strategy balances long-term interests with short-term needs. The health of our science and technology base-our ability to discharge our National Naval Responsibilities, to remain a smart buyer of science and technology, and to get capabilities into the hands of the operating forces—ultimately depends upon a balanced portfolio from basic research through advanced technology development and manufacturing technology.

I especially look forward to incorporating Secretary Gordon England's industry perspective on maximizing the Department of the Navy's precious technology investments.

For the Next Navy and Marine Corps, we are concentrating our science and technology investment into focused programs designed to provide a critical mass of support that will yield Future Naval Capabilities (FNCs). I recently restructured the program to combine overlapping efforts, and I added two programs—Electric Warship and Combat Vehicles Technology (which will focus on bringing the advantages of electrical technologies to the naval warfighters), and Littoral Combat and Force Projection (which includes both combat and expeditionary logistics capabilities), which will focus on Marine Corps requirements in projecting power from the beach in-land. The other ten FNCs (in no priority order) are:

- **Autonomous Operations** will focus on dramatically increasing the performance and affordability of Naval organic unmanned vehicle systems;
- **Capable Manpower** will focus on selection and training to provide fully prepared sailors and marines through human-centered hardware and systems;
- **Knowledge Superiority and Assurance** will focus on issues of connectivity and knowledge superiority for distributed Naval Forces to ensure common situation understanding, increased speed of command, interoperability, and dynamic distributed mission planning and execution across all echelons;
- **Littoral Antisubmarine Warfare** will provide effective capability to detect, track, classify and neutralize all subsurface systems and systems to deny access, in support of power projection ashore;
- **Missile Defense** will focus S&T necessary to detect, control, and engage projected theater ballistic and cruise missiles as well as enemy aircraft threats;
- **Organic Mine Countermeasures** will focus on an organic MCM capability to shorten the MCM tactical timeline and eliminate the need for manned operations in a minefield;
- **Platform Protection** strives to win or avoid engagements with evolving threats either in-stride or while engaged in projecting power from the sea;

- **Time Critical Strike** will focus S&T that provides a substantial reduction in the engagement timeline against time critical mobile targets, theatre ballistic missiles, weapons of mass destruction, C^4I Centers and armored vehicles;
- **Total Ownership Cost Reduction** seeks to significantly decrease costs associated with acquisition, operation and support and to develop methods to accurately predict costs and assess return on investment; and,
- **Warfighter Protection** will focus on protecting warfighters to reduce casualties in the emerging Expeditionary Maneuver Warfare battlespace.

I have directed my people to get close to the Fleet and the Force, to be alert to their needs and swift to respond to them. We are working to enhance their quality of service. As we connect better with our customers—the operating Fleet and Force—we are undertaking some novel initiatives to reduce the cycle time of our technologies. I have established a program I call "Swamp Works." This takes high-risk, high-payoff technologies, puts the right stakeholders together, and gets a product into the hands of the operators who need it. Swamp Works' efforts are intended to be technically risky—I anticipate a 90 percent failure rate—because leap-ahead work is always technically risky. Some of the items I'll show you today—particularly those related to force protection—are Swamp Works projects.

Force protection crosses all technologies. New materials for hull protection, advanced sensors, next generation decision support systems, autonomous platforms, and, ultimately, directed energy weapons—all of these are technological responses to the asymmetric threats our forces encounter as they remain forward deployed.

Another priority I mentioned is human factors and quality of service. Our young people will join and stay with us if we give them meaningful and challenging missions, and if we give them the means to accomplish those missions. The biggest morale-killers on a ship can be those repetitious, labor-intensive, dirty maintenance jobs that have to be done. Naval science and technology offers solutions: coatings that don't have to be scraped and chipped; fault diagnostics that tell you when a bearing is about to fail; condition-based maintenance that saves time and resources. The smart people we have in the Fleet today deserve to work with systems that are engineered with the human being in mind. Human-centric systems, because the system is made for the sailors and marines . . . not vice-versa. These include embedded training that helps sailors and marines work smarter, stay proficient, and learn new skills. There is also no greater satisfaction in sailors' and marines' working lives than accomplishing their mission and getting home to their loved ones.

Below are some of the technologies that I think are steps in this direction, and are examples of our response to the needs of the Navy and Marine Corps of today:

- **Dragon Eye:** The marine sergeant's 4-pound, electronic reconnaissance, backpack aircraft. You launch it by hand and recover it by catching it. If you crack it up, well, that's not a disaster.
- **360° Periscope:** Omnivision extends the view you get through a periscope. It contributes to situational awareness—it helps the submarine commander know what's around him on the surface.
- **Advanced hull forms:** Why should all ships be designed with metal skin frames and stringers? We've been building them that way since they were literally made of animal skins. In particular, why must ships today be built to accommodate a long propulsion shaft? We're moving to an all-electric Fleet, and that means we have an opportunity to experiment with new hull forms, like SEA SLICE, that provide a stable platform in the littorals.
- **Handheld Ultrasound:** Save lives on the battlefield. It enables a corpsman to detect—among other things—internal bleeding.
- **Intelligent Shock Mitigation and Isolation System:** Intelligent use of COTS. This came out of the building industry, specifically, the earthquake mitigation industry. It's going into the LPD–17.
- **High power microwave technologies:** Advanced electronic materials like gallium nitride are revolutionizing this vital area.

Additionally, we are working to field hearing protection systems and vaccines to keep our sailors and marines healthy. We are working on more effective firefighting tools and techniques. We continue to work on environmentally friendly technologies such as the active noise cancellation program that may help our fighter jets to coexist with the ever-increasing civilian population around our bases.

With the assistance and support of the Vice Chief of Naval Research, Brigadier General William Catto, who is with me here today, I focus on the Navy and Marine Corps of today, tomorrow and "after-next" (the one that will fight and win battles in 2020 and beyond). I have given examples above of initiatives in progress for today and tomorrow. The Navy and Marine Corps "after-next" will be based on discoveries just being made today. To ensure we get the technology and development concepts right, a robust cycle of innovation, validated by experimentation that leads to transformation, must continue. It is a process without end; new technologies evolve, new ideas are born, new innovations must be experimented with, resulting in further transformation. It is a process as old as the Navy and Marine Corps, and as relevant as the need for a strong national defense today, tomorrow and always.

The United States has a Navy and Marine Corps second to none in the world, thanks to our volunteers and America's investment in science and technology. I have committed to a science and technology program that ensures our technological superiority continues in this new century—and a program that has the sailor and marine at its center. I hope you will visit the world class Navy/Marine Corps corporate laboratory right here in Washington, DC on the Potomac.

Senator ROBERTS. We will move to Dr. Alexander. Pardon me, Doctor, but because of my interest in the U.S.S. *Cole* and force protection and all that involves, we wanted to get into that, and I apologize to you. Please proceed.

STATEMENT OF DR. JANE A. ALEXANDER, ACTING DIRECTOR, DEFENSE ADVANCED RESEARCH PROJECTS AGENCY

Dr. ALEXANDER. Well, Mr. Chairman, I thank you and the committee for the opportunity to come here today and tell you a little bit about what the Defense Advanced Research Projects Agency is working on.

We are the central R&D organization for the Department of Defense. We can work on problems with individual Services, and we can work in the joint arena and for national command authority problems. Our portion of the R&D portfolio is to emphasize high risk, high payoff, those revolutionary capabilities that lead to big jumps in military capability for the United States.

The other part of our charter says, "Avoid technological surprise." So that means looking into the future 10 or 15 years and anticipating what the opponents of the United States may be doing and come up with technological counters. We cannot prevent them getting their hands on technology, but what we can do is anticipate what advantage they may be trying to derive from that technology and coming up with a counter so that they do not get an advantage.

So that is part of the Department's response to the globalization of technology, especially in the areas of electronics and information technology.

We are going to be facing more and more sophisticated threats, as well as well as asymmetric threats where folks come up with counters to our weapons systems. Adversaries have figured out that if you go force on force against us, you will lose.

We are working in three major investment areas. National-level problems: Those are things that could really pose threats to the Nation. Currently, we are working in the area of biological warfare defense and in cyber defense. We are working in the area of core technologies. These are the breakthrough technologies——

Senator ROBERTS. Let me interrupt for just a minute——

Dr. ALEXANDER. Sure.

Senator ROBERTS. —to indicate that you are right on the money in that respect. We asked people, 3 years ago when this subcommittee was first formed, "What keeps you up at night?" These were the alleged gurus of what could happen down the road in regard to homeland security and force protection overseas.

One thing they said—well, two things, one was cyber attacks or informational warfare; and the other was the biological weaponry which is so easy to use. So you are right on the money.

Dr. ALEXANDER. The second area we are working in is core technology. Those are the breakthrough things that enable the next generation beyond military systems. What we try to do is we look at where industry is going, and if they are already leading in a direction that will support what we need, then we stay out of it. But there are many areas, even in information technology and electronics, where there is a divergence of the military's needs from what the commercial industry will typically give us.

You heard Dr. Etter talk about some of those in the area of radiation hard electronics. That is not one that DARPA is investing in, but we are looking at the wideband gap materials leading to systems that the military needs.

We look for where things may diverge. For instance, in communications technology, in the commercial world, you want to be able to locate the emitter. In the military world, you do not want that to happen because your opponent could then use that as a vulnerability.

The final area that we are working in is operational dominance, coming up with new systems, new technology, combined with concepts of operation that will really give that war-winning capability you heard Under Secretary Aldridge talk about.

I brought a few examples of what is coming out of the pipeline from DARPA today for each of those areas. Starting back with national-level problems, this is in the information assurance area. Working with a small company called, Secure Computing Corporation, they developed some algorithms that are improved firewalls. Actually, most firewall technology in your computer comes from DARPA investment in the early 1990s.

This is the next generation. Firewalls are, in effect, a lock on your front door. But if your opponent gets through the front door, your house is open to them. That burglar can wipe you out. This technology allows you to put a firewall on each and every computer. Your system administrator, through an encoded channel, can change the lock continuously. So if you know you are under attack, then this can be rapidly changed so you have a defense against it.

The company that we funded is now partnered with 3Com. The hardware is on the market now, and the upgraded software that will activate some of the special hardware in here will be on the market in the fall. So that is available.

Could you take that up to the Senators? [Indicating]

In the area of biological warfare defense, I brought you a decontamination solution. What we use currently is bleach. Bleach is very harsh on the skin, and it is very tough on the electronics. We use actually very concentrated bleach on electronics. After only a few times, you can actually destroy the equipment you are having to decon.

This is a very gentle solution. It does not destroy electronics. In fact, it is edible. It can be used to clean wounds. You cannot use bleach——

Senator ROBERTS. FDA-approved edible? [Laughter.]

Dr. ALEXANDER. FDA will—it is actually——

Dr. ANDREWS. It is an herb. [Laughter.]

Dr. ALEXANDER. There are two personal care companies that are thinking about working to license this and to take it to the market. They are actually interested in it's wound cleaning capability, but it also will work for regular decontamination.

Let us see. In the technologies area, we actually did investment in the early 1990s in microelectro mechanical systems (MEMS) technology that has now entered the marketplace, and you think of it as a commercial-off-the-shelf (COTS) technology.

This is a MEMS exploder for a torpedo. [Indicating] The other weighs 17 pounds. The MEMS exploder is 17 times lighter. We worked with the Navy on developing this because they have an anti-torpedo torpedo where the form factor would not take this monster. In here are three COTS MEMS technologies, so things actually had gotten commercialized. In addition, we worked with the Naval Surface Weapons Center (NAVC) on developing two specialized MEMS components. So there are five MEMS components total in here. [Indicating.]

Not only does this do what this monster does, but in addition, it has an inertial navigation system in it. It actually has more functionality in the smaller form factor. So that is an example of where core technologies can lead to breakthrough next generation systems.

Can you hold up the optics?

The normal nosecone of a missile is hemispherical. That is because up until now, that was all you could do and have the correct optical design and the correct ability to manufacture the technology. The problem with that is that very small change in shape can reduce the drag by about half.

What that leads to is a greatly increased distance that the missile can travel with the same propellant, or you could go at a much more rapid speed by being able to make a shape like this called an "A sphere." I brought this with me, just to show you we can make it in any size. [Indicating.]

In addition, we developed both the design software that allows you to figure out how to make those shapes, what shape you want, and we worked with industry to develop the manufacturing tools. The tools are now commercially available to make these. It is transitioning to Army and Navy systems.

Once you go on to—yes, that one. [Indicating.] Captain Kamp, if you could stand up. This is an example of the excellent staff we have at DARPA. Captain Kamp was the originator of the idea of looking at the problem of "How do I deal with diesel subs proliferating and working in the littoral zone?" The idea was to take what in the Air Force is a manned fighter and make it an underwater fighter. So that is the breakthrough idea there, the capability to actively go after opponent submarines in the littoral. What enables this is a new propulsion system, and some new design capabilities in the submarine.

Then finally, we have been working in the area of unmanned air vehicles for a very long time. The Predator that you are used to hearing about from Kosov was actually Project Amber a long time ago at DARPA.

One of the issues with the normal UAVs is that you have to continue forward. They are basically aircraft. The problem with helicopters is they do not have long endurance, and they are manned aircraft if you want to use them as an observation point.

The idea of the A160, working with a small company in California, was to make a very long endurance, 48 hours, aircraft that is helicopter-based, but unmanned so you can use it as an eye in the sky. This is one of the concepts that is being considered for the FCS as part of that system of systems.

So I hope I have given you a little bit of a feel for some of the technologies that are coming out of DARPA. Addressing your question on transition, I think I have given you a feel that some of these we are transitioning through the commercial industry and bringing it to the market so the Department can buy it. In some cases, we are transitioning it into the military program executive officers (PEOs) in order to bring breakthrough capability to our warfighting forces.

Thank you very much.

Senator ROBERTS. Doctor, thank you.

[The prepared statement of Dr. Alexander follows:]

PREPARED STATEMENT BY DR. JANE A. ALEXANDER

INTRODUCTION

Mr. Chairman, subcommittee members, and staff: I am very pleased to appear before you today to discuss DARPA's strategic plan, and to highlight a selection of DARPA's fiscal year 2002 programs.

Let me refresh your memory concerning DARPA's strategic plan. DARPA's mission continues to be to act as the technical enabler for radical innovation for national security. We are pursuing three main mission areas that have endured since DARPA's founding in 1958, even as individual technologies change. DARPA's enduring mission areas are:

- To find technical solutions to National-Level Problems. The Agency's priority is on problems that may impact our national survival.
- To be the technical enabler for the innovation required for our warfighters to achieve dominance across the range of military operations—Operational Dominance.
- To develop and exploit high-risk Core Technologies for our Nation's defense.

In the area of National-Level Problems, DARPA's programs are focused on biological warfare defense and information assurance and survivability. The biological warfare defense effort is developing therapeutics countermeasures, advanced sensors, advanced diagnostics, air and water purification devices, and genetic sequencing codes for potential biological threat agents. In the area of information assurance and survivability, DARPA is developing technologies to raise strong barriers against cyber attack and provide commanders with mechanisms to see, counter, tolerate and survive sophisticated cyber attacks. DARPA invests approximately 15 percent of its annual budget in this mission area.

In the area of enabling Operational Dominance, DARPA is investing in technologies and systems for affordable, precision moving target kill for both offensive and defensive missions and dynamic command and control capabilities for mobile networks and near-real-time logistics planning and replanning. Other programs include technologies and systems that will enable future warfare concepts for air, space, land and sea.

We believe that one key to Operational Dominance will be combined manned and unmanned operations—this will give the future U.S. military an overwhelming edge. Our investments in advanced, high-speed networks, complex system design and operation, wireless communications, microcircuits that combine information technologies and biological systems, and other areas, will enable the U.S. to conduct successful combined manned and unmanned military operations. Providing this technical edge is the key to our involvement with the Army in developing Future Combat Systems (FCS). Our vision for FCS is revolutionary—a network-centric land warfare system of systems composed of manned and unmanned nodes. It will give the U.S. a capability that no other nation possesses.

Our Unmanned Combat Air Vehicle (UCAV) programs are another example of our Operational Dominance investments. We are working jointly with the Air Force and the Navy to develop autonomous unmanned systems that will be able to work with manned aircraft to effectively and affordably suppress enemy air defenses, and for the Navy, also conduct surveillance missions. With these systems, the U.S. will be able to use an unmanned aircraft for dangerous operations rather than put pilots at risk. The unmanned system will operate autonomously within the rules of engagement, in association with manned aircraft, to prosecute its mission. It will not be fire and forget—humans will maintain command and control throughout the mission, and the vehicle will return to base to be used again. This will truly be a revolutionary capability.

The U.S. also must have Operational Dominance in space. The Orbital Express program is developing technologies to allow the autonomous rendezvous, refueling and repairing of satellites on-orbit. This will give us unprecedented abilities to upgrade our space-based assets.

Approximately 40 percent of our annual budget is invested in the Operational Dominance mission area.

DARPA's Core Technology investments include information technology, microsystems technologies, materials technologies, micro-electromechanical systems, beyond silicon complementary metal oxide semiconductor (CMOS) technologies, and investments that combine biology with DOD's traditional strengths in information technologies, electronics, optoelectronics, sensors, and actuators. It is the results of all of these investments that will allow DOD to build systems and capabilities for future operational dominance. In addition, investments in these core areas provide DARPA with a unique outreach into commercial and dual-use technology.

DARPA's investments in information technologies will provide information superiority to the DOD through revolutionary advances in embedded and autonomous systems software; high performance computing components; advanced networking; seamless computer interfaces for the warfighter; ubiquitous computing and communications; and agent-based systems.

In addition, DARPA is investigating chip-scale microsystem technologies that integrate the core technologies of electronics, photonics (light) and micro-electromechanical systems (MEMS). This chip-scale integration offers substantial new opportunities to revolutionize and miniaturize communications, targeting and analytical systems, as well as sensors.

DARPA invests approximately 40 percent of its annual budget in the Core Technology mission area.

I will now go into more detail about DARPA's investments in currently ongoing and planned programs. The Department is in the middle of a strategy review and a Quadrennial Defense Review. As these reviews complete, we may propose changes to some of the details of these efforts. So, with that understanding, I'll launch into an overview of our programs.

TECHNICAL SOLUTIONS TO NATIONAL-LEVEL PROBLEMS

DARPA's charter is to solve national-level technology problems, foster high-risk, high-payoff military technologies to enable operational dominance, and avoid technological surprise. In today's world of emerging asymmetric and transnational threats, our concern focuses on two principal national security issues: protection from biological warfare attack and protection from information attack.

Protection from Biological Warfare Attack

A clear and growing national security need is protection of our military forces from biological warfare attack by both military and terrorist organizations. DARPA's goal is to deter or thwart such attacks with a Biological Warfare Defense thrust focused on sensors, medical diagnostics and countermeasures, air and water purification, pathogen genetic sequencing, building protection, and consequence management.

> "We will work to defend our people and our allies against growing threats: the threats of missiles; information warfare; the threats of biological, chemical and nuclear weapons. . . . We will be creating the military of the future, on that takes full advantage of revolutionary new technologies. . . ."
>
> *—President Bush, January 26, 2001.*

Sensors

To detect the presence of a threat agent, DARPA is investing in the development of advanced Bio Sensors that are robust, autonomous, fast, and sensitive to multiple biological warfare agents. DARPA's mass spectrometer holds the promise of extraordinarily fast and robust identification of all known biological warfare pathogens. The first-generation prototype was evaluated in field trials last year against simulants; based on these trials as well as other technology development, we are now making design and engineering modifications to develop a robust and automated identification and detection capability using time-of-flight mass spectrometry. The program is also developing a nucleic-acid-based microarray sensor to integrate and automate DNA/RNA isolation, labeling, and hybridization procedures into a single platform. The program has already developed a first-generation sensor designed to determine whether anthrax is present, to enable fast separation of hoaxes from real threats. We are evaluating the sensor's performance this year for possible transition to a number of partners, and we are developing an improved, hierarchical sensor in fiscal year 2002.

Another part of the sensor program is investigating whether it is possible to build sensors around cells or pieces of tissue to alert us to the presence of a toxic environment. These Tissue Based Biological Sensor (TBBS) systems use the physiological response of biological cells and tissues to detect biological or chemical threats. The TBBS program is fabricating new devices based on high-density microarrays to detect the presence of engineered agents (or as-yet unidentified threats) for which there are no antibodies or genetic sequences. We constructed laboratory prototypes in fiscal year 2000, including an integrated chip microarray that incorporates liver tissue and measures liver response following exposure to biological agents and chemical toxins. We then took hand-held systems that incorporate electrically active cells into the field at the U.S. Marine Corps base at Twentynine Palms, CA, and tested portable life support systems to provide on-site support for these systems. In fiscal year 2001, we are continuing development of these systems to screen them against a wider list of chemical and biological threats and to determine the limits of sensitivity, false alarm rates, and the effects of interferrants. The Metabolic Engineering for Cellular Stasis (MECS) program complements TBBS efforts. It is investigating biological practices that allow organisms to adapt to environmental extremes and is using those practices to engineer new cellular systems such as platelets and red blood cells. In fiscal year 2000, MECS researchers demonstrated dramatic improvements in the stability of cells by genetically engineering them to increase their resistance to drying for storage. In fiscal year 2001, the program is designing and testing cell and tissue systems that reliably report on viral and bacterial exposures and investigating key sensor features to minimize false positives and maximize signal strength.

Medical Diagnostics and Countermeasures

In the event of a biological attack, the U.S. will need to identify those who have been exposed to a biological warfare agent and to distinguish them from the "worried well," as well as from those with natural diseases that might require different treatment. Therefore, identifying disease markers that can serve as rapid indicators of exposure is one of the focus areas of the Advanced Medical Diagnostics program. One group at Stanford University is looking for genetic markers by testing human cell cultures exposed to a variety of infectious disease agents and other stimuli. In fiscal year 2000, the researchers identified a number of human genes that are selectively turned on or off in response to infection, and in fiscal year 2001, they are testing for these markers in clinical settings such as hospitals. Another activity in this program is identifying markers in breath that may be used to determine who has been exposed to a potential pathogen. In fiscal year 2001, the program identified specific biochemical markers using non-invasive mass spectroscopy that can provide critical information from breath samples. Future studies will look for these markers in breath in models of pathogen exposure (in model systems). In fiscal year 2001, we made significant progress in establishing diagnostic detection equipment based on antibody detection of pathogens. The program transitioned this time-resolved fluorescence technology to the Centers for Disease Control, and it is now being validated for use in public health facilities; the system has been tested against a number of biological pathogens. Rapid sequencing techniques also progressed significantly in fiscal year 2001, and the program is transitioning results to the private sector for further development.

The Unconventional Pathogen Countermeasures (UPC) program is developing broad-spectrum countermeasures for threat pathogens. This includes anti-viral and antibiotic drug discovery and development as well as vaccinations. Three UPC projects, plant-based vaccine production, optimized vaccine development using geneshuffling, and optimization of novel antimicrobial therapeutics, have succeeded in initial DARPA experiments, and we are transitioning them to the U.S. Army Medical Research Institute for Infectious Diseases (USAMRIID) for further development. In addition, the U.S. Army Institute for Surgical Research, Fort Sam Houston, is evaluating skin decontamination by nanoemulsion technology. In fiscal year 2001, we anticipate transitioning other successes to USAMRIID, including novel antibiotic therapeutics, antibiotic target methodologies, and novel DNA vaccines and platforms. A novel vaccine enhancer developed under the UPC program is likely to transition to the Centers for Disease Control or USAMRIID later this year. By fiscal year 2002, we expect to have additional programs ready for transition including vaccine candidates, novel enzyme antibacterial therapeutics, and new approaches to using computers to accelerate the process of discovering therapeutics.

Building Protection

In addition to the component technologies, DARPA is developing complete systems solutions to counter the biological warfare threat. The goal of the Immune Building program, which is just getting underway in fiscal year 2001, is to make military buildings far less attractive targets for attack by chemical or biological warfare agents by reducing the effectiveness of such attacks via active and passive response of heating, ventilation and air conditioning systems and other building infrastructure (neutralization, filtration, etc.). This ambitious goal can only be achieved through a combination of technology development and systems-level experimentation. The program is leveraging earlier efforts in these technologies—for example, decontaminating foams and novel materials that can be used for both chemical and biological filtration—and extending them for use in this application. The program is also developing new component technologies specifically for this application, such as new gaseous decontamination techniques that can follow the contaminant into the small, inaccessible spaces within buildings, specialized low-pressure-drop filtration for use at return vents, and high-efficiency/long-lifetime sources of ultraviolet radiation for on-the-fly neutralization of agents. In addition, several industry teams are evaluating candidate architectures for building protection systems. In fiscal year 2002, the program will test successful technologies and prototypes as parts of complete protection systems, and we will evaluate the most promising architectures experimentally at full scale, as a first step in the design of "optimal" protection systems.

Air And Water Purification

Clean air and water are crucial to the sustained operation of our Military Services in the event of a biological and chemical warfare attack. To-date, our program in Air and Water Purification has demonstrated encouraging results. Warfighters must be able to obtain potable water quickly—their water purification devices and beverage containers must be integrated in order to work and pack away together. One project, the New Generation Hydration System, will produce microbiologically safe drinking water and beverages from sources of unknown quality and will provide an efficient storage and delivery system for hands-free, on-the-move hydration.

One of the program's key design objectives is to be able to purify all available water sources in the field, including desalinating seawater. We plan to meet this requirement by developing a forward osmosis membrane. The program has completed proof-of-principle experiments showing technical feasibility. During the remainder of this year, the program is optimizing the components of the system, e.g., increasing the water flux through the membrane and demonstrating removal of volatile organic compounds and other harmful contaminants from the water. In fiscal year 2002, the program will make the system more rugged and will integrate the forward osmosis component with a standard military hydration bag (such as a Camelback). The Marine Corps plans to transition DARPA's New Generation Hydration System as an official enhancement program.

The Air and Water Purification program is also developing pioneering approaches for advanced gas mask filters. Today's masks have higher-than-desirable breathing resistance, and their capacity (the period of time they effectively filter) is limited. Recently, we have demonstrated the proof-of-principle that microfibrous carriers make better use of carbon to adsorb chemical agents and that they accomplish this with an inherent particulate filtration capability. For the next 2 years, our work is aimed at reducing the pressure drop by at least a factor of two over current C2A1 canisters, while maintaining the equivalent period of time the filters operate effectively.

Protection from Information Attack

The United States possesses limited capabilities to protect against sophisticated cyber attacks. Defending against distributed, coordinated attacks requires technology and infrastructure that commercial industry is not developing. To address this challenge, DARPA initiated the Third Generation Security (3GS) suite of programs to defend the Defense Department's advanced information systems. The goals of these programs are to raise strong barriers to cyber attack and provide commanders with technology to see, counter, tolerate, and survive sophisticated cyber attacks.

In fiscal year 2000, the 3GS suite of DARPA programs made significant progress toward these goals. These programs:

- Developed and demonstrated techniques to detect malicious code and confine damage caused by mobile malicious code;
- Identified survivability principles to allow continued operations through a wide class of cyber attacks;
- Developed distributed security technologies to overcome the limitations of perimeter defense strategies (i.e., firewalls);
- Developed intrusion detection and correlation techniques to enable detection of certain kinds of stealthy network-based attacks and to reduce the overwhelming numbers of security alerts that operators face by recognizing actions that are part of significant multi-step attack scenarios; and
- Developed modeling techniques to determine how the effects of attacks or defensive responses might impact the system's continued ability to perform mission-critical functions.

In fiscal year 2001, the 3GS programs are integrating evolving security technologies to achieve automatic defense, assess correlated attacks, achieve preliminary situation understanding, improve tolerance against intrusion, obtain better assessments of damage and containment, and develop a hardened core. DARPA is using experimentation and technology transition partnerships with operational commanders to evaluate these advanced defensive technologies and transition them to warfighters. Also this year, conceptual system definition studies will begin to apply the results of the 3GS programs to make the DOD's Global Information Grid (GIG) more survivable in the face of cyber attacks. In fiscal year 2002, the suite of programs will use previous system concept studies to design both a survivable prototype of an exemplar GIG system and a Cyber Panel for monitor and control. Next year, the program will:

- Demonstrate the ability of mission-critical systems to operate through cyber attacks;
- Develop a new family of protocols resilient to both service denial and traffic analysis;
- Develop techniques for detecting and correlating disturbances across large networks to allow response to widespread attacks in real time; and
- Develop and demonstrate tools for selecting and carrying out collective defensive actions in response to correlated cyber attacks.

ENABLING OPERATIONAL DOMINANCE

DARPA is the technical enabler for the revolutionary innovation required for our warfighters to achieve Operational Dominance—dominance across the range of military operations. DARPA is emphasizing development of technologies and systems to enable affordable, precision, moving target kill for both offensive and defensive missions. We are also developing technologies and systems to provide dynamic command and control capabilities to our commanders, including the advanced communications and mobile networking technologies necessary for assured communications and information superiority. Other programs focus on technologies to allow planning and replanning in near-real-time. Lastly, DARPA is investing heavily in technologies and systems that will enable future warfare concepts for combined manned and unmanned operations, and operations in space, on land, at sea and in the air.

Affordable, Precision, Moving Target Kill

Current approaches to engaging time-critical surface moving targets include area-of-effect munitions and man-in-the-loop targeting. These approaches traditionally involve large, very expensive weapons, the potential for large collateral damage, and, often, the requirement to put the warfighter in harm's way. DARPA is responding by developing low-cost, highly capable weapons networked to a variety of airborne sensors for offensive and defensive missions, advanced sensors capable of detecting targets hidden in foliage, and camouflage and broadband antennas that can be electronically reconfigured.

The Affordable Moving Surface Target Engagement (AMSTE) program is developing technologies to make it feasible and practical for the warfighter to precisely, rapidly, and affordably engage individual moving surface vehicles. The program will demonstrate that, without expensive modifications to existing and planned systems, networked sensors and weapons can be integrated to provide robust, precise standoff engagement of moving surface targets. In fiscal year 2000, the AMSTE program completed a series of weapon system trade studies that evaluated AMSTE component architectures, developed and performed real-time laboratory experiments to assess the accuracy and robustness of fire control algorithms using radar data collected from multiple airborne sensors, and completed detailed system designs of an experimental AMSTE system. These studies demonstrated the feasibility of the AMSTE concept and identified critical supporting technologies requiring further development and maturation. In fiscal year 2001, the AMSTE program awarded two contracts, to Northrop Grumman Corp. Integrated Systems Sector (Melbourne, FL) and to Raytheon System Co. (El Segundo, CA), to develop and assemble prototype AMSTE experimental systems (representative radar sensors, data links, and weapons) for live flight experimentation. At the end of this year, a series of developmental flight experiments will culminate in the delivery of GPS-guided precision weapons against moving vehicles, targeted by standoff networked sensors using AMSTE precision fire control techniques. Further experimentation with the AMSTE system is planned for fiscal year 2002, and the program will develop and incorporate critical enhancements to address high-confidence track maintenance in highly cluttered environments.

The Advanced Tactical Targeting Technology (AT^3) program is developing and demonstrating technologies that will radically improve today's capability to target surface-to-air missile (SAM) threats through the use of networked, next-generation electronic support measures systems. AT^3 enables the rapid and accurate targeting of precision-guided weapons to counter the modern, more capable enemy SAM systems, which are using increasingly sophisticated tactics such as early emitter shutdown, making them particularly challenging targets. In fiscal year 2000, the program successfully completed initial software algorithm development, non-real-time flight tests, test data analysis, and a critical design review. The data collections focused on a few critical issues: platform-to-platform decorrelation from electronically or mechanically scanned systems, multipath, and geolocation performance. Using realistic emitters, we conducted these tests with a combination of legacy hardware, new AT^3 hardware, and off-the-shelf navigation solutions, and all technical objectives were achieved. The successful conclusion of the tests laid the foundation for our continuing development work in AT^3. DARPA has selected Raytheon Defense Systems Company (Tucson, AZ) to conduct the program's second phase. This year, the program is fabricating AT^3 test hardware, conducting hardware-in-the-loop and ground tests, and continuing software algorithm development. In fiscal year 2002, the program will complete real-time flight tests of the AT^3 packages against real threats, analyze the test data, and continue software algorithm development based on the collected flight-test data.

A new generation of collection systems will provide dramatically increased volumes of high-fidelity data to the operational decision-maker. The challenge will be to manage and synchronize these advanced collection systems with tasking, processing, exploitation, and dissemination capabilities to provide critical information in a constantly changing operational situation. The Advanced ISR (Intelligence, Surveillance, and Reconnaissance) Management (AIM) program is providing the technical foundation for ISR support through the development of an automated system to optimize the tasking of ISR assets to meet users' needs. The AIM program is developing and advancing technologies in areas of multi-node collaboration, semi-automated reasoning, and mathematical programming. The resulting AIM capabilities will transition to DOD automated planning and command, control, communications, computers and ISR (C^4ISR) migration systems as appropriate. In fiscal year 2001, the AIM program is installing the Multi-Asset Synchronizer at the U.S. Southern Command to participate in Exercise Unified Endeavor. AIM is providing enhanced coordination and visualization of multiple diverse collection assets, enabling collection managers to assess the utility of the technology and to provide valuable feedback to guide further development. In fiscal year 2002, AIM capabilities will be further extended to provide near-real-time re-tasking of assets to respond to contingencies and to maximize exploitation system product value.

The goal of the DARPA Counter Camouflage, Concealment, and Deception (Counter CC&D) program is to mature and demonstrate a foliage penetration (FOPEN) synthetic aperture radar (SAR) to provide the warfighter with all-weather, day/night capability to detect targets hidden by foliage and camouflage. In fiscal year 2000, the FOPEN SAR was installed on an Army RC–12 aircraft, and the program conducted preliminary flight tests to validate the real-time image formation software and verify that the system could provide the required image resolution and sensitivity. This year, the FOPEN SAR has demonstrated excellent image quality in the VHF and UHF bands and will complete the preliminary RC–12 flight tests by imaging vehicles hidden under foliage at Camp Navajo, AZ, to establish the capabilities of single-pass and change-detection algorithms. In fiscal year 2002, the RC–12 FOPEN SAR will fly an extensive series of flights to collect the data necessary to train, test, refine and validate algorithms in different foliage environments. The program will also conduct experiments to determine the ability of FOPEN SAR to perform terrain mapping and terrain characterization.

The Symbiotic Communications program will develop a passive, all-weather airborne system that can produce real-time high-resolution synthetic aperture radar images, and very accurate (National Imagery and Mapping Agency level four) terrain height maps, categorize terrain (for example trees versus roads), and detect and locate slowly moving ground vehicles. This system is a passive, bistatic receiver, making it difficult for adversaries to detect and counter the system. This approach will allow our warfighters to gather the battlespace data they need without putting themselves at risk. In fiscal year 2001, an expert Government team and two contractor teams will develop system concepts and ground-based experiments to validate technical feasibility and to refine performance predictions. In fiscal year 2002, the two contractor teams will conduct early flight tests, achieve radar processing of signals of interest, and demonstrate bistatic synthetic aperture radar processing.

DARPA is concerned about the threat of attack by large numbers of low-cost air vehicles—from unsophisticated cruise missiles to small fixed-wing aircraft. This asymmetric threat can emerge very quickly, and there are many ways an adversary can acquire such a threat, e.g., manufacturing them indigenously, importing them from other countries, or converting existing assets. Initiated in 1996, the goal of the Low Cost Cruise Missile Defense (LCCMD) program is to develop a viable, affordable option for countering such an attack without resorting to our current inventory of interceptors (designed for far more sophisticated threats) and running the risk of being overwhelmed by sheer numbers of attacking platforms. The LCCMD program is developing and demonstrating affordable seekers for use on a low-cost interceptor system. Seekers represent approximately two-thirds the cost of a typical interceptor system. Last year, the program conducted laboratory testing of a laser radar seeker and a novel microwave-frequency noise radar seeker. In fiscal year 2001, the program is conducting field-testing of the noise radar seeker and initiating development of an affordable micro-electromechanically switched electronically scanned array (MEMS ESA) seeker. In fiscal year 2002, the program will complete a preliminary design of the MEMS ESA seeker and fabricate subassemblies of its antenna system. The U.S. Army Space and Missile Defense Command has expressed great interest in this program, and has funded an effort this year to evaluate low cost cruise missile defense options.

The Real Time Battle Damage Assessment (RT-BDA) program is developing and demonstrating new techniques to automate the assessment of target battle damage. The program will use tactical and theater synthetic aperture radars coordinated with weapons delivery to image the targets before, during, and following the strike to enable immediate assessment of the strike effectiveness. This year the program is conducting instrumented data collections of real battle damage on realistic targets to produce a database to support further research in signature exploitation techniques. The program is also investigating imaging radar BDA phenomenology and developing prototype RT-BDA detection algorithms and assessing their effectiveness. In fiscal year 2002, we will further mature these initial algorithms to provide damage localization and assessment, and they will be implemented and evaluated in a real-time laboratory system.

The Global Positioning Experiments program addresses the problem of enemy jamming of the Global Positioning System (GPS). The program will demonstrate the use of airborne pseudolites, which are high-power, GPS-like transmitters on aircraft, to broadcast a powerful replacement GPS signal that "burns through" jammers and restores GPS navigation over a theater of operations. Two field demonstrations last year showed that signals broadcast from airborne pseudolites can be used in place of satellite broadcasts to provide good quality navigation to military GPS receivers with only software modifications to the receivers. In fiscal year 2001, the program is conducting laboratory and field tests to demonstrate that beamformer antennas can protect the airborne pseudolite from jamming. In fiscal year 2002, the program will combine these two key pieces of the concept by flying an aircraft in the presence of powerful jamming and demonstrating the ability of a beamforming antenna to allow the aircraft to acquire a satellite signal and rebroadcast it as a pseudolite. Preparations will also begin for a multiple, airborne psuedolite demonstration.

Dynamic Command and Control

One key aspect to operational dominance is the ability of the commander to access critically needed information and to control that information dynamically. Information technologies can provide this ability by allowing disparate information systems and databases to interoperate quickly and efficiently. Other technologies allow commanders to develop operational plans quickly and revise their plans in near real-time to capture new information or counter an adversary's activities. Mobile networking technologies are also important, as future warfare concepts envision small units armed with comprehensive knowledge of the battlespace and able to communicate while maneuvering. The military has a unique need for communications networks that can be formed and reformed rapidly without a fixed infrastructure, and that are highly secure and resistant to jamming; DARPA has a number of investments in these areas. Other programs are focused on the application of information technology to the critical military challenge of controlling and automating the logistics pipeline and planning process.

Near-Real-Time Planning and Replannning

Many recent studies agree that future U.S. adversaries are unlikely to challenge the U.S. directly. Rather, it is more likely that they will present an asymmetrical threat, developing and using approaches that avoid U.S. strengths and exploit potential vulnerabilities using significantly different methods of operation. Adversaries will attempt to create conditions that effectively delay, deter, or counter the application of U.S. military capabilities. DARPA is undertaking high-risk research to help our military and intelligence agencies identify threats before attacks happen. This will allow deterrence or deflection of unconventional but potentially devastating attacks against our military forces and infrastructure. The DARPA Asymmetric Threat initiative will develop a suite of new technological capabilities to better detect, correlate, and understand these asymmetric threats.

The Human Identification at a Distance program began in August 2000. In fiscal year 2001, the Human Identification at a Distance program is developing automated multi-modal surveillance technology for identifying humans at a distance using different biometrics techniques such as face and body parts identification, infrared and hyper-spectral imagery, gait and temporal human dynamics, non-imaging physiological based-biometrics, and remote iris scan. In fiscal year 2002, the program will assess the capabilities of each biometric to identify people at a distance. Based on the assessment, the program will further develop the most promising biometrics and investigate fusion methods.

The Wargaming the Asymmetric Environment (WAE) program will develop and demonstrate specific predictive tools to better anticipate and act against terrorists. WAE is a revolutionary approach to identify predictive indicators of terrorist-specific attacks and behaviors by examining their past behavior in the broad context of their political, cultural and ideological environment. Initial results demonstrate the feasibility of developing automated and adaptive behavior prediction models tuned to specific terrorist groups or individuals. It uses their past behaviors and the consequences of their deeds, as well as the antecedent activities that led up to the act, to predict what, when, where, how and why they will strike next. Over the past year, WAE developed a model able to predict an active terrorist group's next tactic (assault, bombing, assassination, hijacking, or no attack). The model was validated against archival data covering 66 attacks over 17 years. In fiscal year 2001, WAE is expanding its predictive model and validation process to increase the level of detail for predictions of target characteristics, timeframes, geographical location, and motivating factors. In fiscal year 2002, WAE will extend its predictive model development and validation to include other groups and individuals; these models will then be used to develop an intervention-testing environment.

The Evidence Extraction and Link Discovery (EELD) program will develop automated discovery, extraction and linking of sparse evidence in large amounts of classified and unclassified data sources. EELD is developing detection capabilities to extract relevant data and relationships about people, organizations, and activities from message traffic and open source data. It will then link together related items that comprise potential terrorist groups or scenarios, and learn patterns of different groups or scenarios to identify new organizations or emerging threats. EELD's initial activities demonstrated the feasibility of extracting relationships from text and validated the detectability of patterns representing terrorist groups and scenarios. EELD also developed two promising techniques for learning patterns of activity, and developed functional system concepts to guide technology developments. In fiscal year 2001, EELD will develop techniques for evidence extraction, link discovery and pattern learning, validate the detectability of patterns in classified data, and initiate collection and characterization of documents for technology evaluations. In fiscal year 2002, EELD will develop and demonstrate technology to extract relationships, and detect and learn single-link type patterns.

Project Genoa, in the process of concluding, provides the structured argumentation, decision-making and corporate memory to rapidly deal with and adjust to dynamic crisis management. Project Genoa is developing information technology for the intelligence community to rapidly and systematically accumulate evidence, facilitate collaboration while protecting critical information and test hypotheses that support decision-making at the national level. In fiscal year 2000, Project Genoa matured and transitioned a new "thematic" search engine to users on Intelink. Based on successful technology demonstrations, the Defense Intelligence Agency has agreed to be a transition partner for Project Genoa technology. In fiscal year 2001, Genoa evidence-accumulation components are being delivered to the Office of the Secretary of Defense and Joint Staff Directorate for Intelligence (J2), the Joint Counter-intelligence Analysis Group, and U.S. Pacific Command. In fiscal year 2002, these transition activities will be completed.

The Command Post of the Future (CPOF) program is developing tools that enable commanders to rapidly acquire a deep understand of any military situation, leading to faster and better decision making and more effective employment of military forces. In the past year, CPOF has developed several prototypes of the BattleBoard, a mobile command interface that provides the commander with a visual interface to subordinates, superiors, peers, and staff that significantly improves situation awareness and has demonstrated an order of magnitude reduction in time to plan while at the same time improving the robustness of plans. In fiscal year 2001, CPOF is extending research into team collaboration tools and augmenting the collaboration and visualization tools in the BattleBoard with reasoning tools that will provide the commander with the ability to attach intelligent monitors to places, objects, and times in the battlespace, effectively using the BattleBoard as an extension of his memory and expertise. In fiscal year 2002, CPOF will add a dialog system to the BattleBoard providing the commander with richer, more natural ways to query information in the command and control system. Additionally, CPOF will integrate the BattleBoard into existing Army and Marine Corps command and control systems.

The Active Templates program is developing and delivering critical command and control software tools for special operations forces (SOF). These tools enable commanders to plan four times faster, coordinate decisions immediately, synchronize combined-arms operations, and control resources that dictate the outcome of the fight. In fiscal year 2000, the temporal plan editor and execution checklist tool were tested successfully in three SOF exercises and subsequently adopted by a number of SOF organizations. In fiscal year 2001, DARPA is developing a geo-spatial editor for planning and tracking SOF missions on a map or an image. In fiscal year 2002, the program will use default reasoning to develop a networked spreadsheet that allows users to coordinate information, get intelligent assistance for decision-making, and reuse solutions to similar problems solved in the past.

Advanced information technologies are being actively applied to warfighter logistics support, making that support secure, scalable, and robust, and to collaborative logistic and operational planning and execution capabilities for the Global Combat Support System.

The objective of the Advanced Logistics Project (ALP) is to demonstrate the feasibility of using advanced agent-based technology to make a revolutionary improvement in how the DOD provides logistics support to the warfighter. The Advanced Logistics Project is a joint DARPA/Defense Logistics Agency effort, in partnership with the U.S. Transportation Command and the Joint Staff Director for Logistics. The project has developed a distributed systems technology that will revolutionize dynamic planning, execution, and overall information management of the DOD logistics enterprise. In fiscal year 2000, the project dramatically enhanced the architecture to provide the capability to develop and manage multiple concurrent logistics plans. The program worked with the Defense Agencies and Military Services to identify high-payoff pilot projects and developed several applications. One is operational today at U.S. Transportation Command, and another is operating at the Defense Supply Center Columbus, a component of the Defense Logistics Agency, and is scheduled to go into full operation by late June. The program concludes this year having demonstrated a systems architecture that has the capability to: generate an item-level logistics plan in under an hour; totally control the transportation pipeline; continuously generate time-phased support and sustainment demands; monitor the execution details down to the individual items against real-time information from the real world; and dynamically repair the plan when necessary. If this technology were fully fielded in the military, it would allow the military logistics enterprise to: gain control of the logistics pipeline; enable the warfighter to project and sustain overwhelming combat power sooner; permit forces and materiel to be deployed, tracked, sustained, and redeployed more effectively and efficiently with reduced reliance on large DOD inventories; provide users at any level the ability to effectively interact during planning and execution; and, link operations with logistics staff elements at all echelons. As an infrastructure for global logistics, an operational ALP capability would truly enable Focused Logistics as envisioned in Joint Vision 2020.

The Ultra*Log program is developing information technologies to enhance the survivability of large-scale, distributed, agent-based logistics systems operating under very chaotic wartime conditions. This program will build upon—and extend—the revolutionary technologies developed under the Advanced Logistics Project in the areas of security, scalability and robustness to ensure reliable logistics support to the warfighter under the most extreme kinetic and information warfare conditions. If successful, this would serve as a template for creating agent-based distributed command and control systems operating at all echelons that could dynamically recover from information attacks, infrastructure loss, and other real-world problems that plague effective planning and control in complex wartime environments. In fiscal year 2000, the program identified several critical survivability technology extensions such as adaptive communications protocols, layered certificate and encryption-based data security, and techniques for recovery from catastrophic information loss, as well as the processes for measuring and experimentally evaluating them. In fiscal year 2001, the program is concentrating first on building the foundation for survivability in the core architecture to include secure information management, increased fault-tolerance, and system scalability. The program will perform its first large-scale evaluation and assessment in late 2001, to include a Red Team attack of the logistics information system during a representative Major Regional Contingency (MRC) scenario. In fiscal year 2002, the program will focus on expanding the logistics information system's capability to detect threats and change system-state dynamically in response to those threats. The military concept of "ThreatCon" will be incorporated into the software agent architecture to support dynamic reconfiguration for enhanced survivability in increasingly chaotic conditions. In the program's second major assessment in the late 2002, the prototype system will attempt to detect various threats and failures and deploy appropriate countermeasures during the representative MRC scenario.

The primary theme of the Joint Theater Logistics Advanced Concept Technology Demonstration (ACTD) is logistic command and control. The ACTD will leverage current and emerging technology to produce, and rapidly transition, advanced collaborative logistic and operational planning and execution capabilities for the Global Combat Support System (GCSS). It will build a series of web-based Joint Theater Logistics Decision Support Tools that will encourage operations and logistic collaboration during planning and requirements determination and execution tracking, and while realigning resources to meet changing operational situations. The Joint Theater Logistics ACTD will correct existing logistic deficiencies and provide the capabilities necessary to ensure the future coordinated sustainability for logistic operations. This ACTD builds upon the success of the Joint Decision Support Tools and technical architecture developed under the earlier Joint Logistics ACTD, and incorporates technologies from DARPA's Advanced Logistics Project, the Command Post of the Future, and other ACTDs targeted for Joint Task Force operations. The target user for Joint Theater Logistics ACTD is at the operational level: the Joint Task Force, its Service components, and major Service logistics organizations.

In fiscal year 2000, the Joint Theater Logistics ACTD conducted an initial demonstration of collaborative products, allowing operations and logistic users, in real-time via the web, to coordinate shared concepts for planning and execution. This effort included selection of combat and combat support forces, missions, locations, and time phasing. In fiscal year 2001, the Joint Theater Logistics ACTD is demonstrating the ability to collaboratively develop operational courses of action and the corresponding logistic supportability assessments for fuel, engineer, and other commodities in a Joint Task Force environment. In fiscal year 2002, the ACTD will provide a logistic watchboard capability to monitor and replan ongoing logistic operations in real-time, with flexible visualizations to provide rapid drilldown for assessment details. The Joint Theater Logistics ACTD products will transition through the Defense Information Systems Agency in fiscal year 2003 as a Pilot Service Program, with expected fielding to GCSS in fiscal year 2005.

Mobile Networking Technologies

The Airborne Communications Node (ACN) program is developing a multi-mission payload that will simultaneously provide, in a single package, assured communications and radio frequency exploitation (signals intelligence, electronic warfare and information operations) for joint and multinational forces on maneuver. The payload will be scalable for application on a wide range of platforms. It will enable high-bandwidth, beyond-line-of-sight connectivity and will allow the tactical commander to dynamically reconfigure his available assets to satisfy changing mission priorities. In fiscal year 2000, the three competing Phase I contractor teams demonstrated their architecture and proof-of-concept designs for ACN. The program selected two teams to incorporate multi-mission functionality (e.g., assured communications and radio frequency exploitation) into their architecture and begin development of the technologies necessary to implement the multi-mission design. In fiscal year 2001, the program is demonstrating subsystem performance through detailed laboratory testing and simulation. In fiscal year 2002, the program will validate multi-mission functionality in an end-to-end system demonstration in a laboratory environment.

The Small Unit Operations Situation Awareness System (SUO SAS) program is developing and integrating key communications, navigation, and situational awareness technologies for use by light, early-entry forces in restrictive terrain where they currently cannot communicate. The program is developing technologies to enable warfighters to communicate clandestinely in buildings, tunnels, jungles and mountainous terrain using self-forming, computer-controlled networks that continuously monitor the environment, mission needs and the tactical situation, and optimize themselves to ensure that communications are always maintained. These capabilities will greatly increase the effectiveness and survivability of small, dismounted forces. Last year, a series of contractor laboratory and field tests were highly successful in demonstrating SUO SAS' clandestine communications waveform and its non-GPS method for precisely locating soldiers inside buildings. In fiscal year 2001, the program is completing the detailed hardware and software designs, fabricating the major prototype components, and integrating and measuring system-level performance. In fiscal year 2002, the program will complete prototype-level field performance testing and analysis, providing important measures of the technological advances for implementation by the Services in their communications and situation awareness systems. Transition details are currently being discussed with the Army.

The WolfPack program is developing new electronic warfare technologies that can hold enemy emitters (communications and radar) at risk throughout the tactical battlespace while avoiding disruption of friendly military and protected commercial radio communications. The WolfPack concept emphasizes an air-deployable, ground-based, close proximity, distributed, networked architecture to obtain radio frequency spectrum dominance. The WolfPack concept is to use a network of nodes to sense the radio frequency environment, ascertain the type and configuration of the threat, and carry out a precise, coordinated response. That response can either be to disable communications and radar reception, or to relay the geolocation information of the threat transmitter. In fiscal year 2000, a team made up of representatives from government, academia, and industry validated the WolfPack concept and highlighted the critical areas of technology development through analytical assessments of critical technology and performance tradeoffs. This year, the program is starting development of high-risk, high-payoff technologies such as wideband antennas, precision geolocation techniques for urban terrain, spectrum denial techniques for dense threat environments, and extremely small micro-jammers. The program is selecting competing contractor teams to design the system architecture and develop critical component technologies. In fiscal year 2002, the WolfPack program will finalize the system designs and conduct laboratory and limited filed demonstrations of component technologies for network management and emitter node and network identification, classification and geolocation.

Future Warfare Concepts

DARPA is investing in a number of diverse technologies and prototype demonstrations that will enable future operational concepts for a wide variety of critical military missions combining manned and unmanned systems and in space, in the sea, on land, and in the air. The investments for combined manned and unmanned warfare are significant. The autonomous robotics technologies being developed today will allow future warfighters to accomplish their missions more effectively with less risk of casualties, thus preserving the U.S. military's most important resource, its people. In space, we are pursuing revolutionary methods to extend the life of spacecraft while they are on-orbit. We have programs to reduce the frictional drag on ships, analyze future missions for attack submarines, and improve the performance of towed sonar arrays. For land warfare, we are developing a hybrid-electric drive reconnaissance, surveillance and targeting vehicle, covert optical tags for precisely locating objects at kilometer-ranges, and alternatives to antipersonnel landmines. In the air, we are developing active control of flows using a variety of very small-scale actuators, and, based on our success with the Miniature Air Launched Decoy program, we are fabricating a low-cost interceptor to engage enemy cruise missiles.

> "On land, our heavy forces will be lighter, our light forces will be more lethal. All will be easier to deploy and to sustain. In the air, we will be able

to strike across the world with pinpoint accuracy, using both aircraft and unmanned systems. On the oceans, we will connect information and weapons in new ways, maximizing our ability to project power over land. In space, we'll protect our network of satellites essential to the flow of our commerce and the defense of our common interests."

—President Bush, February 13, 2001.

Combined Manned and Unmanned Operations

Flying manned aircraft into hostile territory to strike targets or to suppress enemy air defenses places the aircrews at great risk. The DARPA/Air Force Unmanned Combat Air Vehicle (UCAV) Advanced Technology Demonstration will prove that some of the most hazardous missions can be performed effectively by an unmanned vehicle and made operational by 2010, while, at the same time, reducing costs and risk to human life. DARPA firmly believes that the unit recurring flyaway cost of the UCAV weapon system will be one-third that of the Joint Strike Fighter and that operations and support costs, compared to a current manned fighter squadron, will be reduced by 75 percent. The program began its second phase in 1999, selecting a single contractor to conduct a comprehensive series of simulations, ground tests, and flight tests using a surrogate aircraft, two full-scale air vehicle demonstrators, and a reconfigurable mission control station. The first UCAV demonstrator air vehicle was previewed last year, and the test flight program started this year. The X–45A air vehicle is currently completing engine runs and will systematically move through a series of taxi tests toward a first flight late this Summer. In parallel, a series of simulations will demonstrate the ability of an operator to manage a UCAV in a realistic battle environment. The remainder of the current phase of the UCAV program, extending through fiscal year 2003, will demonstrate: compatibility of the unmanned system with the envisioned 2010 battlespace; robustness and security of communications with the air vehicle; the feasibility of adaptive, autonomous control of the air vehicle, with advanced cognitive decision-aids for the "man-in-the-loop" system operators; feasibility of coordinated, multi-vehicle flight; affordability of operations and support costs; and deployability of the system.

The potential of the unmanned approach to hazardous air missions has also resulted in a joint DARPA/Navy Naval UCAV (UCAV-N) program. The Navy has a need for sea-based, highly survivable, effective and affordable air power to conduct deep strike, suppression of enemy air defenses, and surveillance missions as part of an integrated air campaign. A Naval Unmanned Combat Air Vehicle can prosecute the enemy integrated air defense system and high-value targets with relative impunity without placing a pilot in harm's way. In addition, a UCAV-N capability that can maintain continuous vigilance will enable advanced surveillance, suppression of enemy air defenses, and immediate lethal strike for attacking time-critical targets. DARPA and the Department of the Navy have agreed to a joint program to validate the critical technologies, processes and system attributes and demonstrate the technical feasibility of a UCAV-N system. The UCAV-N Advanced Technology Demonstration program is structured in two phases: first, analysis and preliminary design, and second, development and demonstration. In July 2000, DARPA awarded two Section 845 agreements to Boeing and Northrop Grumman for analysis and preliminary design of a UCAV-N air system, and those studies were completed in March 2001. In April of 2001, the Phase I contracts were modified to permit more complete system preliminary design and to begin risk reduction of critical technologies, processes and system attributes. A successful conclusion to Phase I would lead to a seamless transition into Phase II in January 2002. Phase II will continue through December 2004.

The jointly funded, collaborative DARPA/Army Future Combat Systems (FCS) demonstration program will define the concept design for a new generation of deployable, agile, versatile, lethal, survivable, sustainable and dominant combat systems. The program will develop innovative technologies to get more firepower to the battlefield quickly, establish dominance once there, and reduce the risks to U.S. soldiers. A collaborative system of manned and unmanned platforms is the key FCS enabler. DARPA and the Army are developing the technologies to achieve this new way of fighting, managing the development risks carefully in order to field a highly successful combat system.

The program will develop a preliminary design and fabricate and test an FCS concept demonstrator that will show how the collaboration of manned and unmanned vehicles can establish dominance on the battlefield. At the same time, the program is developing radically innovative enabling technologies for insertion in the demonstrator. These jointly funded enabling technologies will provide mobile, networked command, control, and communications capabilities; autonomous robotic systems;

precision indirect fires; airborne and ground organic sensor platforms; and precision, three-dimensional, adverse-weather reconnaissance, surveillance, targeting and acquisition. In fiscal year 2001, the FCS program entered a competitive concept development phase and is conducting a series of government-run experiments to evaluate the potentially revolutionary impact of various technologies on land warfare. In addition to this design and demonstration effort, DARPA is supporting eight programs to provide supporting technologies:

- The Unmanned Ground Combat Vehicle program, to provide increased mobility, access and flexibility for ground combat units;
- The Perception for Off-Road Robotics program, which will solve problems in autonomous ground vehicle mobility;
- The Organic Air Vehicle program to provide small ground combat units with their own air vehicle for close-in surveillance, reconnaissance and targeting;
- The A160 program, developing a long-endurance, high-altitude rotorcraft for wide-area reconnaissance and surveillance and for use as a communications relay;
- The JIGSAW program, using laser imaging to facilitate the identification of targets hidden under foliage;
- The Command and Control program, which will develop the necessary architecture for a combat system such as FCS with distributed capabilities;
- The FCS Communications program, for the robust, secure links between mutually supporting vehicles needed on the battlefield; and
- The NetFires program, a continuation of the Advanced Fire Support System, to provide precision, vertically launched missiles.

The Unmanned Ground Combat Vehicle program is determining the performance benefits associated with design of ground combat vehicles unrestrained by the need to accommodate a crew. The resulting vehicles are expected to show radical improvements over their crewed counterparts in deployability, endurance, and obstacle negotiation. This program began in fiscal year 2001 and will generate seven preliminary unmanned vehicle system designs for payloads of approximately 330 pounds and 3300 pounds by year-end. These payloads are notionally associated with sensor missions and sensor plus weapons missions. In fiscal year 2002, the program will select at least four designs to conduct critical subsystem testing (power systems, suspensions, structural dynamics, and controls) in conjunction with design refinement in preparation for prototype fabrication, which should begin in the Summer of 2002.

The Perception for Off-Road Robotics program is determining the extent of autonomous ground navigation that can be achieved in the near-term to support tactical assumptions being made for robots in FCS. This program is structured around unscripted field testing of multiple perception approaches using state-of-the-art sensors, algorithms, and processing capability in a wide variety of environmental conditions. Example multiple perception approaches include dual perspective sensing with a small unmanned air vehicle assisting the ground vehicle, or combined active and passive sensing with radar and infrared sensors. Some approaches also use strong adaptive learning algorithms to place sensor data in the context of the local terrain and simplify the identification of hazards. The field tests will incorporate on-the-fly learning by the robots and operation in coordinated teams (including unmanned air vehicles). This program began in fiscal year 2001 and will involve four competing perception system teams, each preparing two surrogate vehicles for autonomous mobility and perception testing in fiscal year 2002. In fiscal year 2002, three of these approaches to participate in field testing in forest, desert, mountainous, and outdoor urban terrain under both day and night conditions. These tests will be used to refine the algorithms and assess the performance (and potential performance) of each approach under these widely varying conditions. The results will provide validated data for FCS simulation models.

The purpose of the Organic Air Vehicle (OAV) program is to provide ground combat units, including Future Combat Systems units, with a capability to detect adversary troops concealed in forests or behind buildings or hills—anywhere that U.S. forces do not have a direct line-of-sight to the hostile force. Today the military must send out human scouts to locate and identify enemy troops, a slow and dangerous process. The air vehicle will be small, lightweight, and inexpensive enough to be carried, launched, and operated by lower-echelon ground units. The goal is that the OAV design be less than one foot in any dimension, weigh less than two kilograms, and cost approximately $1,000 each in quantities of 100,000 or more (cost for the air vehicle without payloads). The air vehicle will carry a variety of sensors, such as LIDAR, infrared, or electro-optic devices to detect vehicles or individual soldiers.

Initial testing of an OAV candidate, the Lift Augmented Ducted Fan vehicle, was completed satisfactorily last year. In fiscal year 2001, we will conduct flight tests of promising vehicles and develop flight control software. The program will finalize integration of complete, scalable vehicles and sensor packages in fiscal year 2003.

The Hummingbird A160 program is developing a revolutionary advancement in the capabilities of helicopters. The program began in 1998 to satisfy a military need of the Army and the Marine Corps for an affordable, vertical take-off and landing unmanned air vehicle with a long ferry-range (greater than 2,500 nautical miles) and high-endurance (greater than 24 to 48 hours) capability with substantial payloads. The A160 is also being developed as a sensor and communications platform for U.S. Special Operations Command and the DARPA/Army Future Combat Systems program. Automated flight controls and an automated ground station will allow operation of the aircraft with minimal operator training. The flight control system and ground station were demonstrated successfully last year with a surrogate unmanned helicopter. The rotor system was also demonstrated on a ground-based rotor test stand in the past year, and the first A160 air vehicle is expected to begin flight-testing this year. In fiscal year 2002 and 2003, the A160 program will integrate and demonstrate several surveillance payloads.

The Jigsaw program is developing LADAR sensors to enable combat identification by humans. Unlike video data, LADAR sensors will provide three-dimensional information that can penetrate holes in foliage and assemble information from multiple viewpoints as the sensor moves around the potential target. This program, which started in fiscal year 2001, is collecting experimental data mimicking FCS environments and is developing software to perform the assembly and visualization of three-dimensional information. In fiscal year 2002, the program will build prototype LADAR sensors with integrated software to perform experiments in realistic scenarios.

The objective of the FCS Command and Control program is to develop an integrated command and control system for the Future Combat System Unit Cell that enables two to six people to command all organic assets, both manned and unmanned, in combat. Since the proposed area of influence, operational reach, and lethality of the cell's organic assets are comparable to that of a current operational battalion, this program is attempting to reduce the command and control staff by a factor of 10. The current battle command approach is stovepiped in nature and is not integrated. The operational constructs of FCS dictate the need for a responsive, integrated command and control system to support this new approach to distributed networked battle. The program began in October 2000, and has mapped information flows, tasks, operational constructs and technical build requirements for the integrated command and control architecture. This year, the program continues research in integrated battle command and modeling and conducts an initial pilot test simulation of a unit cell in combat. We begin a series of four experiments in integrated battle command in October 2001, with the final experiment planned for April 2003.

The objective of the FCS Communications program is to create a real-time, mobile, ad hoc network capable of operating with the extremely low probability of detection and robustness to jamming necessary for positive robotic and fire control requirements. In fiscal year 2001, the program selected contractors to develop critical enabling technologies: high band technology for dynamically exploiting millimeter-wave frequencies; low bandwidth (e.g., future Joint Tactical Radio System) technology for dynamically exploiting complex radio frequency environments; mobile ad hoc network technology for smoothly blending the high bandwidth and low bandwidth technologies into an assured single network; and network modeling and simulation. In fiscal year 2002, the program will down-select to a single team for system integration and demonstration.

The Future Combat Systems and the U.S. Marine Corps' concept for Operational Maneuver from the Sea both envision the use of forces rapidly deployed by air and sea that need to be able to call upon precision, responsive firepower guided by beyond-the-horizon targeting. The NetFires program is developing a family of small, container-launched missiles to provide massive, responsive, precision firepower early in a conflict and is a key element supporting beyond-line-of-sight engagements for the DARPA/Army Future Combat Systems program. NetFires is designed for low logistics burden and low life-cycle cost: a single C–130 could deliver a shipping container with 150 NetFires missiles capable of engaging 150 separate targets up to 200 kilometers away. The system is shipped in its launching container, requires no additional launch support equipment, and can be fired remotely from trucks, HMMWVs, or a variety of other platforms. NetFires' rounds are ready to fire immediately, resulting in a much higher potential rate of fire than is possible with current howitzers or missile launchers. Last year, the program tested both a variable thrust motor, a key enabling technology, and a launcher. This year we are continuing to verify the operation of the variable thrust motor, having successfully demonstrated maximum-flight-duration motor burn-times. Both missile contractors have successfully conducted their first boost test vehicle launches, and we are conducting seeker captive flight tests and extensive wind tunnel tests; air drop tests of the loitering attack missile will take place this summer. Initial unguided air vehicle flight-testing begins this year, and extensive, fully integrated missile flight-testing will be conducted in fiscal year 2002 and 2003.

One key to developing intelligent, autonomous, unmanned platforms is advanced software. The Software for Distributed Robotics (SDR) program is developing robot software technologies to allow a single soldier to interact naturally with and intuitively control a large swarm of very small micro-robots performing a collective task. In fiscal year 2000, SDR demonstrated statistically grounded, probabilistic control algorithms suitable for directing the actions of a dozen micro-robots. In fiscal year 2001, the program is demonstrating the ability of a single soldier to control the behavior of a swarm of 100 simulated micro-robots. In fiscal year 2002, SDR will demonstrate these ensemble behaviors on a swarm of 100 physical micro-robots and will transfer the software to physical robot platforms.

Space Operations

The Orbital Express program is designed to create a revolution in space operations. It will demonstrate the feasibility of refueling, upgrading, and extending the life of on-orbit spacecraft. Automated spacecraft will perform all of this space work, lowering the cost of doing business in space and providing radical new capabilities for military spacecraft such as high maneuverability, autonomous orbital operations, and satellites that can be reconfigured as missions change or as technology advances. Giving military satellites the capability to maneuver on-orbit would provide them with dramatic advantages: they would be able to evade attacking spacecraft and could escape observation by making their orbits less predictable to adversaries. Last year, the program selected multiple contractor teams to recommend the optimum architecture for an on-orbit servicing infrastructure. The teams reported to DARPA on the space missions they determined would benefit the most from being serviced, e.g., surveillance satellites that could be maneuvered to coordinate overhead coverage with air strikes to provide timely battle damage assessment if they could be refueled, or space based radars that could be upgraded with faster processors instead of waiting for new satellites to be launched. In fiscal year 2001, the teams are designing a pair of spacecraft for an on-orbit demonstration of the enabling technologies needed to make on-orbit servicing feasible—autonomous guidance, navigation, and control software to control satellite rendezvous and proximity operations, sensors to measure and match relative satellite motions, wide capture-range grapple and soft docking mechanisms, and open satellite bus architectures that can accept plug-in upgrade components. The program will select one team to build components necessary for the on-orbit demonstration and continue development of key technologies. Fabrication and ground-test of the two space vehicles will continue through fiscal year 2004, with launch of the space experiment anticipated for late 2004.

The Coherent Communications, Imaging and Targeting (CCIT) program could lead to more efficient systems for tracking satellites and transmitting communications to them from mobile platforms. Current systems, which use adaptive optics (flexible mirrors whose surface can be changed to compensate for atmospheric aberrations or distortions), are too heavy to use in mobile platforms. The CCIT program will demonstrate aberration-free communications, imaging, and tracking using the coherent properties of laser light and aberration correction devices that employ micro-electromechanical (MEMS) technology. Fiscal year 2001 is the first year of the program, and we are designing and modeling the CCIT system and developing aberration correction. The program is developing three device types, and we will assemble the most promising into a laboratory CCIT system in fiscal year 2002. All three Military Services are potential customers as CCIT provides capabilities for secure communications.

Maritime Operations

The goal of the Robust Passive Sonar (RPS) program is to significantly increase the performance of tactical towed sonar systems by canceling out surface shipping noise, the primary cause of interference. The RPS program accomplishes this cancellation by innovative and optimal processing techniques coupled with multi-dimensional receive arrays and other external information. The expected net system performance gain is 10 to 20 decibels, and the system is expected to dictate future array and acoustic sensor field designs. Last year, the program began development of the space-time processing algorithms to reject interference. In fiscal year 2001, the program is beginning development of a processing system that will integrate the various algorithms and is also planning an initial data collection exercise. In fiscal year 2002, the program will conduct data collection exercises with the Navy and carry out a preliminary performance assessment of the integrated system.

The Submarine Payloads and Sensors Program was a joint DARPA/Navy program to investigate missions for attack submarines in the future, the payloads and sensors needed to conduct these missions, and the impact of these changes on the overall submarine design. Two consortia, formed in 1999, provided final reports to DARPA and Navy last year, and program management of this effort has transferred to the Navy this year. Concepts generated under the study will enable the Navy to investigate new payload and sensor technologies for its *Virginia* class submarines. In fiscal year 2002, DARPA is evaluating the results of the study in consideration of other DARPA investments in maritime technologies. Several innovative technologies in underwater propulsion concepts, underwater littoral warfare concepts and antisubmarine research can be combined to enable new warfighting capabilities. One such idea is a very fast, highly agile underwater fighting vehicle employing vortex combustor technology for propulsion and advanced sensor technologies for targeting surface ships and submarines in the littoral regions.

The Buoyant Cable Array Antenna (BCAA) program is developing a submarine phased array antenna in a towed buoyant cable format, which will provide high bandwidth, full duplex communication capabilities while a submarine is operating at speed and at depth. Over the next decade, increased emphasis on joint littoral operations, network centric operations, and advanced threat sensor systems will overwhelm the submarine's operational connectivity. In fiscal year 2000, the program developed and tested antenna and transmit algorithms in controlled environments, i.e., laboratory and in-water conditions. In fiscal year 2001, DARPA is conducting open-ocean testing of the antenna system to demonstrate critical performance milestones. Fiscal year 2002, the integrated system will be fabricated, deployed from both a surface ship and a submarine, and tested at sea to demonstrate high bandwidth connectivity from a submarine.

The Friction Drag Reduction (FDR) technology program is developing a multiscale modeling capability for turbulent flow to allow ship designers to decrease friction drag by at least 30 percent with a commensurate increase in endurance and/or payload fraction and possibly significantly increasing speed. Using recent advances in computational technology, FDR will examine whether injecting polymers and microbubbles will achieve these goals. In fiscal year 2001, DARPA is modeling different drag-reduction mechanisms. In fiscal year 2002, DARPA will continue modeling activities, and begin system optimization and design of near full-scale laboratory experiments.

Ground Operations

The Antipersonnel Landmine Alternatives (APLA) program is focused on long-term alternatives to antipersonnel landmines that would prevent adversaries from maneuvering at-will. The Self-Healing Minefield is developing an antitank minefield that completely eliminates the need for antipersonnel landmines. The military uses antipersonnel landmines within an antitank minefield to prevent dismounted soldiers from finding and disabling the antitank mines. In the Self-Healing Minefield, no antipersonnel landmines are used. Instead, antitank mines detect a breach attempt via mine-to-mine communication and the minefield responds by self-repositioning a fraction of the mines remaining in the minefield to fill in the breach. In fiscal year 2000, the program began designing and testing three concepts for the antitank mine mobility system and communication system, investigated behavioral responses to breaching, and completed preliminary field-testing of a liquid fuel-based hopping mobility system. During fiscal year 2001, the program is testing and refining the three system concepts, culminating with the construction of at least 10 prototype inert mines for each concept. During fiscal year 2002, the program will complete final testing of the first generation prototype mines at Fort Leonard Wood, MO.

The Reconnaissance, Surveillance and Targeting Vehicle (RST–V) program will develop, demonstrate and transition to the Services four hybrid-electric drive, lightweight, highly maneuverable advanced technology demonstrator vehicles that can be transported inside a V–22. The RST–V's compact, V–22 airlift-requirements-driven design also makes it attractive for transport in a wide variety of aircraft, including the CH–47 and CH–53 helicopters and the C–17 and C–130 fixed-wing aircraft. The vehicle will incorporate advanced integrated survivability techniques and an advanced suspension. It will carry integrated precision geolocation, communication and reconnaissance, surveillance and targeting sensor subsystems. The RST–V platform will provide small-unit tactical reconnaissance teams, fire support coordinators, and special reconnaissance forces with quick deployment and deep insertion of a multi-sensor vehicle to provide battlespace awareness. Last year, the first two vehicles rolled out and the program demonstrated the ability to transmit digital video and to operate using battery-only mode, diesel-engine-only mode, and diesel-electric hybrid mode. In fiscal year 2001, the program is participating in the U.S. Navy Extending the Littoral Battlespace Advanced Concept Technology Demonstration and U.S. Marine Corps Capable Warrior Advanced Warfighting Experiment to demonstrate the silent watch/silent movement capability of a hybrid-electric vehicle. During the experiment, Force Reconnaissance Marines will conduct a reconnaissance, surveillance, and targeting mission using the RST–V's integrated command, control, communications, computer, and intelligence/reconnaissance, surveillance, target acquisition communication and sensor suite digitally linked into the Extending the Littoral Battlespace wide-area network architecture. The third and fourth vehicles will also be rolled out this year. During fiscal year 2002, the vehicles will undergo survivability, automotive, and active suspension performance testing.

The Optical Tags program is investigating optical technologies and innovative design and fabrication techniques for covert, kilometer-range, optical tags systems for downed pilot extraction, covert tracking, and precision targeting. Specific applications will be selected based on their operational significance and user input, and then demonstrated in meaningful warfighter experiments. During fiscal year 2001, appliqué-based tags are being fabricated and demonstrated at kilometer ranges. A live technical demonstration for early-entry and special operation forces is planned for late-Summer 2001, when we will demonstrate specific vehicle identification within a convoy, individual soldier identification and location marking applications. During fiscal year 2002, the program will begin investigating precision strike applications and conduct engineering tests of improved tags in a more stressing, operationally realistic situation.

The Tactical Sensors program is developing the architecture, sensors, and other technologies to incorporate unattended ground sensors into the suite of tools useful to the warfighter for detecting and classifying time critical targets. The system will consist of miniature, low-power internetted unattended ground sensors, deployed in clusters and fused with longer-range space and airborne systems. In fiscal year 2001, the emphasis is on quantifying system performance, developing target classification algorithms, and initiating planning tools. In fiscal year 2002, the program will finalize the system design and build a number of systems for demonstration and validation in the field.

Air Operations

The Small Scale Propulsion Systems program is developing a new class of propulsion systems that will be smaller than any existing engines, i.e., less than seven centimeters diameter and generating thrusts of less than 10 kilograms. The new engines will enable development of very small missiles to use against small targets, small unmanned vehicles for close-in surveillance, and new space-launch vehicles. Engines being developed include a shirt-button-sized turbo-jet engine, a rocket engine only 12 millimeters wide by five millimeters thick, an efficient and high-thrust seven-centimeter diameter turbo-jet, and a pulse detonation engine. During fiscal year 2000, the program began detailed design of the engines. During fiscal year 2001, the program is completing detailed designs, finishing the fabrication of the button-sized turbo-jet engine, and testing the pulse detonation engine prototype and the turbo-pumps for the 12-millimeter rocket. The program will finish fabrication and testing in fiscal year 2002.

The performance of any system that travels through air or water is dominated by the ability to control the flow over its surfaces. To-date we have been limited to passive control methods such as surface shaping. Recent advances in very small-scale actuators are being used in the Micro-Adaptive Flow Control (MAFC) program to enable active control of flows using a variety of very small-scale actuators. The MAFC program combines adaptive control, distributed sensor arrays, and advanced miniature actuators to provide a closed-loop control system for a particular application. The program is beginning to demonstrate revolutionary performance improvements for aerospace and marine applications. Performance improvements as large as 30 percent have been achieved, with momentum inputs 10 to 50 times smaller than those used in conventional systems. MAFC technologies are being explored for a wide range of applications, including: adaptive lift-on-demand for agile weapons and uninhabited aircraft; lightweight gas-turbine engines; control of cargo aircraft jet engine exhaust on the ground for safe loading operations; and steering projectiles for extended range and precision. In addition, MAFC technologies hold promise for improved payload capacity for rotorcraft, enhanced aircraft maneuverability, extended vehicle range, and decreased fuel burn at lower total system cost. The applications are guided by system-level performance benefits and cost assessments. In fiscal year 2001, several promising control devices are testing protocols and demonstrating open-loop flow control. We tested a prototype full-scale flow control system on a C–17 engine and established that it would not adversely affect engine performance. An active hover download alleviation system for the V–22 performed better than expected at one-tenth scale, with a 20 percent increase in overall vehicle lifting capacity; testing will progress to one-quarter scale in fiscal year 2002. The program will demonstrate fully integrated MAFC subsystems in fiscal year 2002 and fiscal year 2003.

DEVELOPING AND EXPLOITING HIGH-RISK, HIGH-PAYOFF TECHNOLOGIES

DARPA continues its traditional investments in information technology, microsystems technologies, advanced materials, and micro-electromechanical systems (MEMS). It is the results of these investments that allow us to build the systems and capabilities for operational dominance of the future. In an exciting new initiative, BioFutures, we have begun to invest in programs that lie at the intersection of biology, information technology, and the physical sciences, having realized that the biological sciences, when coupled with DARPA's traditional strengths in materials, information, and microelectronics, could provide powerful approaches for addressing many of the most difficult challenges facing DOD in the next 15 to 20 years. In the Beyond Silicon Complementary Metal Oxide Semiconductors (CMOS) thrust, we are pursuing a radically different approach to the fabrication of logic and memories, enabling enormous gains in computational power in smaller and smaller devices.

Information Technologies

DARPA's investments in information technologies will provide information superiority to the U.S. military through revolutionary advances in:

- Design methodologies for embedded and autonomous systems software;
- High performance computing components;
- Networking;
- Seamless computer interfaces for the warfighter;
- Ubiquitous computing and communication resources; and
- Agent-based systems.

Information technologies such as computing and networking have come a long way, but their future remains unlimited. New technologies offer great promise, e.g., wireless and power- and energy-aware computing devices, embedded computers (that is, computers interacting in real-time with networks of sensors and actuators), wideband optical networks, MEMS, quantum devices, cognitive neurophysiology, and computational biology and bio-informatics. However, these new technologies also require additional development if DOD's future computing systems are to be able to take full advantage of them.

Embedded and Autonomous Systems Software

As computers are increasingly embedded in the real world with networks of actuators and sensors interacting with physical devices in real-time, it is important to design middleware for connecting the computing intelligence to the physical system. Advanced weapon systems are increasingly becoming totally dependent on the efficacy of their embedded computing systems. Consequently, as we endeavor to improve the functionality of military systems, either for reasons of greater autonomy or higher performance requirements for the warfighter, we must develop methodologies, tools, and technologies for embedded software that are:

- Verified and validated by design so as to reduce the need for extensive testing;
- Reasonably well separated from the underlying computing platform to enable their upgrade as new processors become available; and
- Composable so as to allow for the addition of new functionality without extensive rewriting of the legacy code.

As DOD systems increasingly transition from platform-centric to network-centric weapons systems, developing a new generation of technologies that can greatly enhance the adaptivity, assurance, and affordability of embedded software is essential for U.S. national security. To address this need, the Program Composition for Embedded Systems (PCES) program is creating new technology for programming embedded systems that will substantially reduce development and validation effort and improve the flexibility and confidence of the resulting software. The technology produced by the PCES program in fiscal year 2000 has been used to refactor complex monolithic operating systems into modular components that can be reassembled rapidly to build custom embedded control systems. In fiscal year 2001, the program is developing and applying static analysis techniques for real-time embedded systems' properties and demonstrating these techniques to enhance the performance and robustness of operational avionics mission computing systems. In fiscal year 2002, the PCES program will develop and apply intermediate representations and mechanisms for code composition and transformation that will synthesize adaptive software to control and enhance the quality of service properties of data-streaming missions performed by advanced unmanned air vehicles.

The Mobile Code Software program develops software technology to resolve time-critical constraints in logistics and mission-planning, including integrated maintenance and mission planning to support the operation of Marine Attack Squadrons, real-time mission planning and dynamic replanning experiments for unmanned combat air vehicle operation, and adaptive scan-scheduling for electronic warfare platforms. Demonstrations of Mobile Code Software in real-time, distributed, resource management of radar sensors for tracking moving objects showed that negotiation-based approaches can meet the time requirements of electronic warfare applications. The Mobile Code Software program solves the resource management problem through the interaction of lightweight, mobile software components. We use a bottom-up organization approach and negotiation as techniques for resolving ambiguities and conflicts to get logistics and mission-planning solutions that are both "good enough," and "soon enough." In fiscal year 2000, Mobile Code Software successfully demonstrated real-time negotiation technology in mission planning with users at Marine Aircraft Group 13, Yuma, AZ. In fiscal year 2001, the program is scaling-up the technology to demonstrate integrated mission planning and maintenance planning using real-time negotiation. In fiscal year 2002, Mobile Code Software will demonstrate rapid, dynamic, negotiation-based re-planning in highly decentralized environments and in electronic warfare applications.

The Mobile Autonomous Robot Software (MARS) program is developing software technologies that can enable machine-learning strategies to automatically generate sophisticated robot behaviors such as autonomous navigation and real-time obstacle avoidance. These sensor-mediated behaviors will reduce the requirement for remote operator control for robots employed in tactically realistic environments including complex, dynamic environments such as urban combat battlespaces. In fiscal year 2000, MARS demonstrated a suite of off-line learning technologies that can rapidly generate desired robot behaviors with minimal hand coding of the control software. In fiscal year 2001, the program is demonstrating on-line learning techniques that can automatically generate desirable, adaptive behaviors without human intervention. The ultimate goal is to allow the warfighter to task a robot in the same terms as he or she might task a human. In fiscal year 2002, MARS will demonstrate a trainable, perception-based autonomous indoor navigation capability.

The goal of the Software-Enabled Control (SEC) program is to leverage increased processor and memory capacity to achieve higher performance and more reliable software control systems for mission system platforms. Military applications include integrated avionics design and vehicle control for high-performance unmanned air vehicles (UAVs) and unmanned combat air vehicles (UCAVs), as well as upgrade potential for existing airframes such as the F–15E, F–18, and AV–8B. This research will yield control technology that is robust enough to withstand extreme environments and to enable highly autonomous, cooperating mission systems. In fiscal year 2000, the SEC program designed an open software architecture for hybrid discrete and continuous control that supports better integration of control mode logic with continuous control laws, including synchronized switching and new software scheduling mechanisms. In fiscal year 2001, a prototype implementation of the hybrid multi-mode control software is being completed for single-vehicle uses, including predictive modeling of environmental effects (e.g., wind gusts, turbulence) and safely controlling mode transitions under such effects. This technology will provide enhanced maneuverability/evasive capability for UAV/UCAV systems and enhanced robustness under extreme conditions for piloted systems, increasing the warfighter's survivability and decreasing his workload. Multi-modal control technology will provide better-controlled transitions between complex operational flight modes (inherent in vertical takeoff and landing UAVs and high performance/transonic manned aircraft), thereby reducing safety risks to the warfighter and vehicle. In fiscal year 2002, the program will develop adaptive hybrid control services to ensure stable operation and extend the control software design to support highly coordinated control of multiple platforms. Coordinated multi-modal control technology will simplify the task of controlling groups of unmanned vehicles, increasing the capacity of a single warfighter to safely control large numbers of air and ground vehicles. This technology will directly support management of authority within groups, supporting the ultimate goal of enabling safe combined manned and unmanned operations.

From avionics systems to smart weapons, embedded information processing is the primary source for superiority in weapon systems. The new wave of inexpensive MEMS-based sensors and actuators and the continued progress in computing and communication technology will further accelerate this trend. Weapon systems will become increasingly "information rich," where embedded monitoring, control and diagnostic functions penetrate deeper and with smaller granularity in physical component structures. Virtually all new and planned weapon systems illustrate this trend: proposed future functionally integrated but physically distributed "open flat avionics architectures," inherently distributed architectures for National Missile Defense and Future Combat Systems, mission control software architecture for UCAV, and many others. These systems all require solutions that the Networked Embedded and Autonomous Software Technology (NEST) program is developing: application-independent, customizable, and adaptable services for the real-time "fine-grain" distributed control of physical systems. The quantitative target is to build MEMS-based, dependable, real-time, embedded applications comprising 100 to 100,000 computing nodes. In fiscal year 2001, NEST is designing Open Experimental Platforms (including a "smart structure" and a distributed vehicle application), challenge problems, and NEST integration frameworks. The smart structure application provides active, acoustical/structural mode damping and adaptive damage identification in payload fairings. The distributed vehicle application implements closed-loop coordination among large number of sensors and micro-vehicles in pursuer-evader simulations. In fiscal year 2002, the program will demonstrate the scalability and fault resilience of basic coordination service components in 100-node, simple network embedded software technology applications using lightweight, wireless communication networks.

High Performance Computing

DARPA's investments in information technology are also providing technology and tools to design high performance computing components that are adaptable (i.e., the computer hardware can be modified by its own software), with processors embedded close to the memory to prevent data starvation and allow power- and energy-aware computing.

Many defense applications such as dynamic, sensor-based processing, battlefield data-processing integration, and high-speed cryptographic analysis are data-starved—that is, the processor is so fast that it has to wait for memory to be accessed from random access memory between operations, thus slowing down the computation. Prior analysis showed that memory access was growing at the rate of 7 percent annually, while Moore's Law predicted the doubling of processor speed every 18 months. This program is aimed at reducing this imbalance.

The Data Intensive Systems program is developing innovative data access techniques to solve this problem and enable new military capabilities. For example, if the processing portions of the computer architecture are physically closer to the memory location, data can be retrieved more quickly. In fiscal year 2000, the program designed and simulated intelligent memory controllers, adaptive caches, and memory systems. In fiscal year 2001, we are completing the concept development and testing of the early prototypes and demonstrating a 16-fold improvement in the speed at which memory is made available to the processor for data intensive applications.

Energy and power management has now become a critical factor for future embedded and large scientific computing applications. The Power Aware Computing/Communication program is developing an integrated software/hardware power management technology suite comprised of novel techniques that may be applied at all levels of a system—from the chip to the full system. This will enable embedded computing systems to reduce energy requirements by a hundred- to a thousand-fold in military applications ranging from hand-held computing devices to unmanned air vehicles. In fiscal year 2000, we began power aware computing and communications research, metrics, and mission scenarios. In fiscal year 2001, the program is evaluating and prioritizing individual power aware technologies for components, micro-architectures, compilers, operating systems, and algorithms. In fiscal year 2002, power management technologies will be demonstrated showing a potential 10-fold power/energy savings for multiple candidate DOD platforms and missions, including Land Warrior Dismounted Soldier, distributed sensors, and unmanned combat air vehicles.

Networking

DOD applications are highly bandwidth-intensive, and their demanding requirements cannot be met by the commercially developed networking technologies that are optimized for web browsing and low data-rate data streaming. The Next Generation Internet program, ending this year, has developed the key technologies, both in hardware and software, to enable access to extremely high bandwidth. The program has deployed a national-scale SuperNet test bed that ties together several dozen sites at multi-gigabit rates. A number of high-speed, end-to-end networking records were established during our experimentation. These early experiments also revealed the vulnerability of existing networking protocols to bandwidth-intensive flows, and have stimulated a number of efforts to streamline the networking protocol. This year, the new protocols that enable high-speed access at 40 gigabits per second are being integrated into network interface cards and tested along with all-optical burst switches.

The Gigabyte Applications program is developing technologies for a highly robust, high-speed networking infrastructure in a heterogeneous environment. By extending high-bandwidth capability to wireless links, it will be possible to deploy high-speed networks with many hundreds-of-megabit- to gigabit-per-second capacity in remote tactical locations with no pre-existing fiber infrastructure. Such links will also enable high-speed reach back to a command post or to the U.S. This can be contrasted to approximately 20 megabits per second connectivity made available to a handful of U.S. installations during the Bosnia conflict—a speed totally inadequate for distributing sensor output, maps, high-resolution imagery and other intelligence data in real-time. The program is also developing key DOD applications that take advantage of a robust capability to stream gigabytes to terabytes of real-time data. In fiscal year 2001, the program is testing multi-antenna wireless networking technology that has the potential for gigabit end-to-end radio frequency connectivity. In fiscal year 2002, the program will demonstrate the sparseband sensor processing technology, where multiple gigabit per second streams from radars operating in different bands or locations are networked and coherently processed to dramatically enhance the sensitivity and resolution that could be attained from independent sensors.

Seamless Computer Interfaces

The Translingual Information Detection, Extraction, and Summarization (TIDES) program is creating technology to enable English speakers to locate and use network-accessible information in multiple languages without requiring knowledge of those languages. Last year TIDES started developing key component technologies and cooperated with Third Fleet in a field experiment called Strong Angel that applied early versions of the technologies to humanitarian assistance and disaster relief operations in a mock exercise in Hawaii. In fiscal year 2001, TIDES is making the technologies more robust and using them in a more ambitious experiment called Integrated Fleet Experiment-Bio (IFE-Bio), aimed at global infectious disease monitoring, that will be conducted in Bedford, MA, and San Diego, CA. In fiscal year 2002, the program will add cross-document, cross-language summarization and translation capabilities and will conduct experiments in additional languages of defense interest, including Chinese and Arabic.

Ubiquitous Computing

Miniaturized, low cost sensors will become more capable and pervasive in future military systems to detect ground-moving targets and biological and chemical warfare agents, and for military operations in urban terrain. To fully utilize these sensor capabilities, we must develop software that can create an ad-hoc network of deployed sensor devices, and process information collected by the sensors for reconnaissance, surveillance, and tactical uses for the warfighter. The Information Technology for Sensor Networks (SensIT) program is producing software that enables flexible and powerful sensing capabilities for networked micro-sensors. During fiscal year 2000, the program developed new algorithms for ad hoc sensor networks, and methods for cooperative sensing. The initial version of the SensIT software with dynamic programming ability was demonstrated at the U.S. Marine Corps base at Twentynine Palms, CA, where extensive data from acoustic, seismic, infrared and other sensors was collected to develop micro-sensor network methods for detecting, classifying, and tracking ground moving targets and communicating this data to (and receive tasking instructions from) a remote site. In fiscal year 2001, the program is developing an integrated software suite and conducting field demonstrations, also at Twentynine Palms, CA. This demonstration will include inter-networking of ground sensors with sensors on mobile platforms such as unmanned air vehicles, predicting target movements, imaging the targets and relaying the image data to a command center for confirmation. In fiscal year 2002, the program plans a field demonstration and two joint experiments with the Marine Corps. These demonstrations will feature fully integrated software that highlights the new operational capabilities of low-latency networks of programmable, multi-modal microsensors for rapid tracking of ground moving targets and for detecting and classifying of threats in urban environments.

A grand challenge for information technology is bridging the gap between the physical and digital worlds. Computers should disappear into the background while information becomes ubiquitous. The Ubiquitous Computing program focuses on developing the underlying technologies to provide accessible, understandable, relevant information to mobile users, based on an understanding of the user's tasks and informational needs, to provide the user with greater and more timely situational awareness—thereby increasing his survivability, lethality, and effectiveness. In fiscal year 2000, the Ubiquitous Computing program delivered several products, including: a small foot-print operating system, TinyOS, that enables self-organization of small computing devices, such as those in the SensIT distributed sensor network vehicle tracking demonstration; an initial, component-based architecture to provide seamless computing support to mobile ground troops, enabling them to have access to digital information needed for their tasks; and an architecture to support secure, mobile access to "persistent data," i.e., data that must be stored and accessed for some period of time, such as logistics and casualty information. In fiscal year 2001, the program is developing software components to support nomadic data access and representations for task-level computing.

Agent-Based Systems

The DARPA Agent Markup Language (DAML) program is creating technologies that enable software agents to identify, communicate with, and understand other software agents dynamically in a web-enabled environment. Agents, which are software programs that run without direct human control or constant supervision to accomplish goals specified by the user, can be used to collect, filter and process information—a crucial need of command, control, intelligence, surveillance, and reconnaissance applications. DAML is developing an extended XML markup language that ties the information on a page to machine-readable semantics, thus creating an environment where software agents can function. This effort will provide new technologies for operational users by integrating information across a wide variety of heterogeneous military sources and systems as the technologies are deployed in both command and control and intelligence applications. Last year, in the first year of the program, DAML developed the first working draft of the software language and coordinated it with the World Wide Web Consortium. In fiscal year 2001, the program is releasing working versions of Briefing Tools, Search Tools, and Ontology Creation Tools, and is defining and testing a toolset for military applications of DAML technologies. In fiscal year 2002, the program will deploy the DAML Search tool on an operational Intelink node and prototype selected DAML tools to enhance search and retrieval tools at the Center for Army Lessons Learned and other military and civilian venues.

Information superiority in the modern battlefield requires that the military be able to rapidly assemble a set of disparate information systems into a coherently interoperating whole. This must be done without system redesign and may include interoperation with non-DOD governmental systems, systems separately designed by coalition partners, or commercial-off-the-shelf and open-source systems not built to a pre-existing government standard. The Control of Agent Based Systems (CoABS) program is building on the technology of run-time interoperability of heterogeneous systems to develop new tools for facilitating rapid system integration. Last year, CoABS developed and demonstrated a flexible information infrastructure and an interoperability tool called the Agent Grid, which supports the dynamic deployment of complex applications for military command and control. The Agent Grid was demonstrated to the U.S. Army Communications-Electronics Command Research, Development and Engineering Center (CECOM), Fort Monmouth, NJ, and to the Air Force Research Laboratory (AFRL), Rome, NY. CECOM is now investigating the Agent Grid for use in their battlefield command and control systems, such as the Maneuver Control System, and AFRL is experimenting with the Agent Grid to solve interoperability issues for Air Force missions. In fiscal year 2001, CoABS is using agent technologies and tools in military scenarios to demonstrate the run-time integration and interoperability of heterogeneous systems in applications that address present and future command and control problems. In fiscal year 2002, CoABS will transition run-time integration capabilities to the Military Services by providing the command and control infrastructure for Joint Forces Command's Millennium Challenge '02, operating in the Army's Agile Commander Advanced Technology Demonstration, and facilitating new operational capabilities for the Air Mobility Command.

At present, complex military problem-solving tasks are either performed totally by human operations officers and intelligence analysts, or with minimal assistance by small knowledge bases. Computer scientists trained in artificial intelligence technology must formulate these knowledge bases. The Rapid Knowledge Formulation (RKF) program is developing methods to conduct rapid database searches, construct knowledge bases, and draw inferences for key information. The RKF program is enabling end-users to directly enter knowledge into knowledge bases and to create massive knowledge bases (106 axioms) in less than 1 year. It will allow artificial intelligence novices to directly grasp the contents of a knowledge base and to compose formal theories without formal logic training. As a result, it will enable military and technical subject matter experts to encode the problem-solving expertise required for complex tasks by directly and rapidly developing, extending, and expanding small knowledge bases by a factor of 10. Because these knowledge bases are required for analysis of hardened and deeply buried targets, offensive and defensive information operations, and weapons of mass destruction capability assessments of terrorist organizations, the capabilities enabled by RKF will be extremely useful. The RKF program began in fiscal year 2000 and demonstrated a language and diagram interface, analogic reasoners, and theory explanation capabilities; it also developed 10 to 20 core theories. In fiscal year 2001, RKF is demonstrating direct knowledge entry by a single, novice user at a rate of 2,000 axioms per month entered into a knowledge base that addresses malaria and orthopox (smallpox) biological weapon threats, vaccines and other countermeasures. By the end of fiscal year 2002, RKF will demonstrate knowledge entry of a biological warfare challenge problem at a rate of 50,000 axioms per month from each of 25 subject-matter experts.

Microsystems Technologies

DARPA's pursuits in microsystems technologies are driving a new chip-scale revolution in electronics, photonics, and micro-electromechanical systems (MEMS) while demonstrating revolutionary display technologies and photonics for military information systems.

The objective of the University Opto-Centers program is to establish multi-investigator university optoelectronic centers with programs closely coupled to photonic industry researchers to develop and demonstrate chip-scale optoelectronic integration technologies. The development of advanced, chip-scale optoelectronic modules is essential for future, high-performance military sensor and information processing systems. University-based research provides the knowledge base and the highly capable expertise to both innovate and support the development of these capabilities within industry. In fiscal year 2000, the University Opto-Centers established new capabilities for the design, fabrication and demonstration of chip-scale modules that integrate photonic, electronic and micro-electromechanical systems-based technologies. The program also established university technology research goals and identified methods to facilitate industry access to these technologies. In fiscal year 2001, the program is evaluating specific chip-scale integrated module designs and assessing the success of engaging industry commitment to the program. In fiscal year 2002, the program will fabricate and test individual chip-level sub-assemblies for later use in prototype development.

The Flexible Emissive Display program was established in fiscal year 1999 and is developing and demonstrating large-area, high-resolution, flexible, emissive, rugged displays for DOD applications. The development of rugged, lightweight, inexpensive, flexible displays will be useful for aircraft, ships, land vehicles, and foot soldiers. In fiscal year 2000, the program conducted demonstrations in all three key technology areas: backplanes, emissive materials, and substrates. In fiscal year 2001, the program is demonstrating a low-cost, high-speed, roll-to-roll assembly process for plastic-film liquid crystal displays and is demonstrating a flexible, lightweight, emissive, color, electroluminescent display based upon plastic material. By the end of this fiscal year, the program will have demonstrated emissive color display video capable of greater than 80 lines per inch on a flexible substrate.

The primary human-machine interface remains the visual display of information. The DOD has a diverse range of needs for display technology, and today most of these needs (approximately 80 percent) can be met by commercial parts, while the remaining require ruggedized or custom design and manufacture to meet performance requirements. DARPA's High Definition Systems (HDS) program, ending this year, began 13 years ago and invested over $650 million in display and related technologies. The HDS program has played a significant role in meeting today's DOD display needs. At the start of the program, cathode ray tube technology dominated most applications. Liquid crystal displays (LCDs) were just beginning to emerge as an alternative, primarily for power-efficient, lightweight laptop computer applications. The primary suppliers of these technologies were in Japan and were unwilling to work with DOD contractors. Today, for most of the displays important to the DOD, LCDs continue to dominate, but new technologies are emerging that include MEMS mirror arrays, light emitting diodes (LEDs), and thin film electro-luminescence displays. These latter types of displays are available from both domestic and international sources, but the dominant LCD suppliers are still centered in the Far East (Korea, Taiwan and Japan). However, the market for LCDs is highly competitive, presenting a robust marketplace in which DOD suppliers have ready access to the most advanced technologies.

Specific HDS program successes include: MEMS-based Digital Micromirror Device technology, which is finding application in the Common Large Area Display Set for Airborne Warning and Control System, Joint Surveillance and Target Attack Radar System and E–2C airborne systems and UYQ–70 aboard ship; cholesteric liquid crystal technology that can maintain a static image without consuming power and is finding application for information management systems by the Army Military Police; small (one-inch) active matrix LCD for use in head-mounted displays being transitioned to the Army's new reconnaissance/attack helicopter, the RAH–66 Comanche; and low-voltage thin film electro luminescence displays for the forward looking infrared displays in the Army's Abrams M1A2 System Enhancement Program. A major investment area for the HDS program has been in developing flexible emissive displays, including organic light emitting diodes and flexible substrate technologies. These technologies are becoming available but face considerable manufacturability and long-term reliability challenges. However, they offer the promise of roll-up or "window-shade" displays for compact, portable command and control applications. In addition, the HDS program has supported, on a cost-shared basis, the U.S. Display Consortium (USDC). The USDC is made up of U.S. display industry companies and provides support for the development of display manufacturing equipment, processes and materials. The Consortium has completed more than 40 projects, including 25 that resulted in commercialization of new tools or materials for fabricating LCD, electro-luminescent or organic light emitting diodes.

Relative to defense needs, today's truly global market for high definition displays and the far greater commercial applications of these devices has resulted in an advantageous position for the DOD. The DOD strategy as we go forward is to make use of the global industrial capability where it is available, using existing acquisition guidelines, with contractors buying most display components in a highly competitive, rapidly evolving and increasingly robust market place. In the future, DARPA will limit its research and development investments to focused specific needs where industry is not yet leading the way and a military advantage is foreseen.

The Photonic Analog-to-Digital Converter Technology program will apply photonic technologies to improve analog-to-digital converter performance to achieve 12- to 14-bit resolution at sampling rates up to 10 giga-samples per second. Sampling at these very high rates enables use of more complex radar waveforms and improved signal-to-noise performance, providing enhanced resolution and improved target imaging for military radar systems. The ability to directly perform analog-to-digital conversion of multi-gigahertz signals at the source, while preserving their entire spectral content, will have significant impact on the performance of a wide range of radar, electronic warfare and communication systems and create new architectural possibilities for these systems. In fiscal year 2000, the program evaluated alternative designs for the optical clock, optical sampler, and electronic quantizer modules. In fiscal year 2001, the program is completing the initial photonic analog-digital converter evaluation and finalizing the design for the demonstration module. In fiscal year 2002, the program will integrate the photonic clock and sampler modules with electronic quantizers and complete analog-to-digital converters with at least 10 gigasamples per second.

Traditional approaches to electronic interconnects based on wire interconnection lead to information processing systems that are bulky, heavy, and power-hungry. The communication bandwidth and speed possible with these electronic interconnects is lower than that of the processor itself, leading to bottlenecks within the system. The Very Large Scale Integration (VLSI) Photonics program is developing photonics technology that uses optical links instead of electronic wire links for chip-to-chip and board-to-board communications. This new technology will allow data transfer rates faster than a terabit per second, which is crucial for high-speed processing applications such as synthetic aperture radar and automatic target recognition. In addition, VLSI Photonics will enable a 100- to 1000-times reduction in power and size for these systems.

The most important accomplishment in the VLSI Photonics program has been the demonstration of the capability to manufacture vertical-cavity surface-emitting lasers with yields of over 99 percent on large-area (three-inch) wafers. Technology for manufacturing conventional lasers will never achieve this low-cost, large-area capability. Surface-emitting lasers have demonstrated the lowest threshold currents of any lasers ever manufactured, with estimated lifetimes of well over 50 years. In fiscal year 2000, the program used optical links to transfer useful data between chips to allow benchmarking performance against traditional electrical approaches. We are planning the two major capstone demonstrations of the program for the third and fourth quarters of fiscal year 2001, the program's final year. The first involves data processing in synthetic aperture radar, and the second in hyperspectral imaging. Both of these applications generate large quantities of data that are currently difficult to process in real-time. The reduced size of the optical components and increased data processing speed will demonstrate the feasibility of achieving more than 100-times reduction in power-volume product for synthetic aperture radar two-dimensional fast Fourier transform computations. This program has successfully captured the interest of systems designers, including commercial high-end workstation designers, and has stimulated the creation of at least two start-up activities to pursue the continued development of the technology.

Thermal imaging remains a cornerstone technology for many military applications, including small unit operations, ground, air and sea target acquisition, missile seekers, and threat warning. Significant strides have been made in converting thermal imaging technology from cryogenically cooled detectors to uncooled thermal detectors, which have the potential to improve detector performance by a factor of 10. The Uncooled Infrared Integrated Sensors program has catalyzed a major shift in focal plane array technology. For many years, the standard uncooled array was based upon a pixel size of 50-by-50 micrometers and an array format of 320-by-240 picture elements. This relatively large pixel size limited both the system resolution and target acquisition range, and most importantly, restricted the options available to the system designer. Last year, this program demonstrated for the first time the ability to fabricate uncooled infrared sensors with a pixel size of 25-by-25 micrometers, a 75-percent reduction in area. Although thermal sensitivity should be reduced for smaller pixels, the sensitivity was maintained at 0.050 degrees Kelvin, exceeding current uncooled performance. These efforts will truly revolutionize thermal imaging, providing lower cost sensors for current systems and allowing the integration of imaging micro-sensors into novel platforms such as micro air vehicles and robotics. A 320-by–240 array incorporating this structure demonstrated two times the target acquisition range of the typical uncooled infrared sensor. In fiscal year 2000, the program began the investigation of new concepts for thermally sensitive microstructures. In fiscal year 2001, the program is demonstrating a 100-gram imaging sensor with performance acceptable for micro air vehicles. In fiscal year 2002, the program will incorporate high responsitivity materials into the detector structures and integrate materials and microstructures into imaging arrays. This will establish the viability of high-performance uncooled infrared, providing acceptable thermal imaging performance in a package 10 to 100 times smaller and at one-tenth the cost of current thermal imaging sensors.

The objective of the Photonic Wavelength and Spatial Signal Processing program is to develop integrated electronic and optoelectronic device and module technologies that allow the dynamic and reconfigurable manipulation of both the wavelength and spatial attributes of light for adapting, sensing and image pre-processing. The reconfiguration and data pre-processing capabilities of these technologies will allow the design and manufacture of real-time sensing and imaging systems. These systems could be deployed in a wide variety of tactical systems, such as night vision systems, early warning sensors, and autonomous platforms. This will be a significant improvement over the current generation of sensing and imaging systems, most of which are not capable of real-time data collection, analysis, and presentation. The technology will allow hyperspectral imaging in real-time in a single, chip-scale microsystem. The data contained in a given scene will be processed, in terms of spatial and spectral content, on-chip at the sensor/imaging array through the heterogeneous integration of detector arrays, micro-optics, and controlling electronics. This approach will result in greater than an order of magnitude reduction in the amount of data that must be transmitted to a user, thereby reducing demand on constrained bandwidth links. Furthermore, since processing is done at the sensor, faster and more reliable decision making will be enabled, e.g., rapid detection, identification, and classification of chemical and biological agents. The same suite of technologies can also be used in the detection and recognition of targets and objects that are otherwise obscured from view. During fiscal year 2000, the first year of the program, we developed the basic source and detector device technologies that cover spectral bands between 350 nanometers and 14 micrometers. In fiscal year 2001, the program is demonstrating emitters and detectors in the spectral band 350 to 500 nanometers. In fiscal year 2002, the program will develop micro-machined optical elements for the spectral band 300 to 500 nanometers and three to five microns in the infrared band.

The Advanced Lithography program is seeking solutions to critical technical barriers in emerging microcircuit fabrication technologies that are essential to improving the computational speed, functionality, size, weight, and power requirements of microelectronics. These performance improvements will benefit essentially all advanced military systems, including computation and signal processing for communications, sensing, and guidance systems. In fiscal year 2000, the program developed key tool components, materials and processing to accelerate the availability of emerging lithography technologies beyond 193 nanometers. In fiscal year 2001, the program is demonstrating key components of a maskless wafer writer and key components for lithography of 0.07-micron features. In fiscal year 2002, the program will develop key tool components, materials and processing for both maskless and projection approaches for lithography at 0.05 microns and will fabricate prototype devices for military applications with features of 0.1 micron in size. The fiscal year 2002 budget level for the Advanced Lithography program will reflect and support the semiconductor industry's decision regarding next generation lithography; they decided to pursue extreme ultraviolet lithography as opposed to optical and x-ray lithography technologies. DARPA's Advanced Lithography program will therefore reduce investments in those areas while concentrating on leading edge technologies critical to military needs—maskless and nanolithography. DARPA will continue to push the leading edge of lithography into the sub–35 nanometer range, while industry provides the engineering developments for next generation lithographies. In addition, DARPA initiated a broad effort to identify and develop the next-generation of microcircuitry components to overcome the traditional limits of current silicon technology. This effort, Beyond Silicon Complementary Metal Oxide Semiconductors, is discussed later.

The objective of the Three-Dimensional Imaging program is to develop the ability to rapidly capture a three-dimensional image of a target and determine its detailed target profile. This will significantly enhance the ability to identify targets in cluttered backgrounds and to correctly identify friendly versus unfriendly targets. Imaging from fast-moving platforms and the requirement to rapidly engage multiple targets necessitates the development of an imaging array, which, using a single flash of laser illumination, provides both intensity and target depth information. The Three-Dimensional Imaging program focuses on the materials, detector, and unique electronics technology required to obtain, in a single, very short-duration, eye-safe laser pulse, a target depth profile or three-dimensional image of the target. Key innovations in the technology are the ability to incorporate gain into the detector structure, fabricate focal plane arrays of high-gain detectors sensitive at short-wave infrared wavelengths, and to integrate range-processing circuitry into the unit cells at each detector. In fiscal year 2000, the program evaluated fundamental materials properties necessary to fabricate high-gain detection devices in the short-wave infrared wavelengths, with a focus on material defect reduction and the uniformity enhancement necessary for array development. This year, the program has demonstrated a four-by-four detector array with a gain of 30 at one gigahertz and will complete investigations of novel high-gain detector concepts. In fiscal year 2002, the program will demonstrate a low-power system with a range resolution of one to six inches at one to two kilometers.

The Steered Agile Beams (STAB) program is developing small, lightweight laser beam steering technologies for the replacement of large, mechanically steered mirror systems for free-space optical communications and infrared countermeasures systems. New solid-state/micro-component technologies such as optical MEMS, patterned liquid crystals and micro-optics will provide the opportunity to incorporate small, ultra-light, rapidly steered laser beam subsystems into a broader range of military platforms and man-transportable applications. These advanced subsystems will enable laser designators to simultaneously engage multiple targets, increase both smart weapon kill ratio and delivery platform stand-off distance (and, therefore, launcher survivability), allow full 360-degree infrared countermeasures coverage around aircraft and other high-value military assets, and provide a secure, covert means of high-bandwidth transmission programs for special operations forces and scout intelligence preparation of the battlefield. During fiscal year 2000, the program determined the optimum mix of technologies to be developed, and established STAB system architectures and performance objectives for subsystem components to form the basis for managing risk and technical progress. In fiscal year 2001, the program is developing, fabricating and evaluating the beam steering, emitter, and detector components and downselect the most promising approaches. In fiscal year 2002, the program will develop design goals for assembled components and fabricate individual laser beam steering components.

High-performance radio frequency systems are critical to a wide range of advanced military radar, electronic warfare and secure communication applications, but they are currently restricted to deployment on large weapons platforms due to the size, weight and power characteristics of electronics-based radio frequency components. The Radio Frequency Lightwave Integrated Circuits program will develop smaller, lighter, yet higher performance photonics-based radio frequency components capable of operating over a much broader range of radio frequencies, while also providing the form factors required by the small and rapidly mobile weapons platforms of the future. This program, which began in fiscal year 2000, is identifying promising approaches to photonic components or enhanced radio frequency applications. The first year was spent developing radio frequency photonic modules that enable links with zero net radio frequency loss from input to output and demonstrating optically integrated modules capable of performing complex radio frequency functions. In fiscal year 2001, the program is identifying key applications for integrated radio frequency photonic modules, producing initial prototypes, and demonstrating methods to evaluate their performance. In fiscal year 2002, the program will integrate recently developed emitters, waveguides, detectors and integrated circuits to produce radio frequency photonic component prototypes.

Advanced Materials

DARPA's Structural Materials program is tailoring the properties and performance of structural materials to lower the weight and increase the performance of defense systems. Technologies are being pursued that will lead to ultra-lightweight ground vehicles and spacecraft through the use of structural amorphous metals or multifunctional materials. The program is also developing improved body armor for the individual soldier.

The Multifunctional Materials program explores materials that combine the function of structure with another critical system function (power, repair, ballistic protection, etc.). For example, in fiscal year 2001 the program is demonstrating the use of fuel cells whose physical structure also serves as the functional structure for the system or platform, significantly reducing the parasitic weight of power generation in weight-sensitive micro air vehicles. An example is a micro air vehicle with a wing that is the structure, the antenna, and the fuel cell wall (hydrogen inside, air outside). In fiscal year 2002, the program will investigate structures that combine ballistic protection with structure.

The goal of the Lightweight Body Armor program is to significantly reduce the weight of soldier body armor designed to stop 30 caliber armor piercing bullets to an aereal density of 3.5 pounds per square foot. Three ultra-lightweight body armor concepts, two of which use active armor techniques, are supported by the U.S. Army Training and Doctrine Command Systems Manager-Soldier. The DARPA program is the first to investigate how active armor systems could be safely and effectively employed for personnel protection. This year, the program is selecting the most viable concept for further development, with subsequent demonstration of an armor system by the Army planned for fiscal year 2002.

The Structural Amorphous Materials program exploits the truly unique properties (toughness, strength, ballistic properties) of structural amorphous materials for critical defense applications such as ballistically resistant ship structures and as a replacement for depleted uranium in anti-armor projectiles. In fiscal year 2001, we are developing approaches for processing these advanced materials in bulk at reasonable cost. In fiscal year 2002, we will evaluate the properties of these materials in the context of making significant improvements for defense applications.

The objective of the Mesoscopic Integrated Conformal Electronics (MICE) program is to be able to create electronic circuits and materials on any surface, e.g., to print electrical circuits on the frames of eyeglasses or interwoven with clothing. The MICE program will provide a number of benefits to the DOD. The ability to print ruggedized electronics and/or antennas on conformal surfaces such as helmets and other wearable gear will provide new capabilities and functionalities to the future warfighter. MICE technologies will eliminate the need for solder, thereby greatly increasing the robustness of electronic circuitry, and the need for printed wiring boards, enabling significant weight savings for a number of military electronic platforms. To accomplish these objectives, the program is developing manufacturing tools that directly write or print electronic components such as resistors, capacitors, antennas, fuel cells, and batteries on a wide variety of substrates and with write speeds that approach or exceed commercial printing technologies—all at significantly decreased processing complexity and cost. Recent efforts have demonstrated the ability to print metal lines on curved surfaces, feature sizes as small as five microns, and print speeds close to one meter per second. One of the most exciting developments has been the demonstration of printed zinc-air batteries that have four times more volumetric power density than commercial batteries. With these demonstrations in hand, industry is moving forward with plans to use MICE tools for printing batteries, fuel cells, conformal antennas, and circuit interconnects. Plans for upcoming years include printing high-gain antennas on conformal surfaces, printing solar cells and fuel cells for integrating energy sources with the electronics, and making high-quality electronic parts at very low temperatures.

The Smart Materials and Structures Demonstrations program has applied existing smart materials in an appropriate device form to reduce noise and vibration and to achieve aerodynamic and hydrodynamic flow control in various structures of military interest. These devices can facilitate a paradigm shift for the design of undersea vehicles, engine inlets, aircraft wings, and helicopter rotor blades. Demonstrations have included small, high-bandwidth devices for acoustic signature reduction of marine turbo-machinery, shape memory alloy (SMA) actuators to control the shape and attitude of fighter inlets to achieve higher aerodynamic efficiencies and performance, flexible skins with embedded SMA wires that permit continuous control surface shape changes for improved aerodynamic performance (Smart Wing), and small, powerful actuators capable of fitting into the confined interior space of a rotating helicopter rotor blade for noise and vibration reduction (Smart Rotor). We are also exploring novel ways to make compact hybrid actuators that will employ smart material driving elements to create a new class of efficient, high energy density actuators in a package that is smaller and lighter than conventional hydraulic and electromagnetic actuators with similar power ratings. These new actuators could lead to considerable weight savings and reduced complexity and maintenance in smaller aircraft and have applications to the control of new types of hypersonic missiles. We concluded the marine and aircraft demonstrations earlier this year, and will conduct the final Smart Wing wind tunnel test of a scale-model unmanned combat air vehicle in the NASA Langley Transonic Dynamics Tunnel later this year. Construction of full-scale helicopter rotor blades in the Smart Rotor effort is currently underway, and wind tunnel and whirl stand tests are planned for late 2001. The overall goal of the Smart Rotor effort is to successfully demonstrate acoustic noise and vibration reductions in a flight test aboard an MD900 Explorer in early 2002.

The Exoskeletons for Human Performance Augmentation program is developing technologies to enhance a soldier's physical performance to enable him, for example, to handle more firepower, wear more ballistic protection, carry larger caliber weapons and more ammunition, and carry supplies greater distances. This will provide increased lethality and survivability of ground forces in combat environments, especially for soldiers fighting in urban terrain. Working with significant interest and technical input from the operational military, we are exploring systems with varying degrees of sophistication and complexity, ranging from an unpowered mechanical apparatus to full powered mechanical suits. The program is addressing key technology developments, including energy-efficient actuation schemes and power sources with a relevant operational life, active-control approaches that sense and enhance human motion, biomechanics and human-machine interfaces, and system design and integration. In fiscal year 2000, the program evaluated innovative actuation concepts using chemical energy sources such as hydrocarbon fuels to provide mechanical motion. In fiscal year 2001, researchers are developing, characterizing and testing integrated technologies, activities that will continue in fiscal year 2002.

Biomimetic technologies look for inspirations from biological systems to create hardware with superior capabilities. One focus of the biomimetics efforts in the Controlled Biological and Biomimetic Systems program is to explore the unique mobility offered by legged platforms. The program designed small, legged robotic vehicles (the size of a shoebox) for fault-tolerant mobility over rough terrain where wheeled and tracked vehicles often fail. Field-testing with the Marine Corps has demonstrated that these platforms have significant mobility in operational environments such as urban terrain where large obstacles and unplanned rough terrain impeded mobility. Preliminary assessment of the six-legged platforms called Rhex and Scorpion have shown superior performance in benchmarking tests against wheels and tracks and in operational environments of interest. The program now plans to explore developmental prototypes and define additional military utility for these legged robotic vehicles. We are interested in including additional fundamental principles of legged performance, new biomimetic structural and functional materials and enhanced software. The program will ultimately add sensor payloads for navigation and guidance and to perform specific military applications such as reconnaissance, or identification and removal of unexploded ordinance.

The Functional Materials program is developing non-structural materials and devices that enable significant advances in communications, sensing and computation for the military. Examples include: magnetic materials for high sensitivity, magnetic field sensors and non-volatile, radiation-hardened magnetic memories; light-emitting polymers for flexible displays; and frequency-agile materials based on ferrite and ferroelectric oxides for high sensitivity, compact tuned filters, oscillators, and antennas. In fiscal year 2000, the program demonstrated light-emitting polymers for flexible displays with performances almost equivalent with inorganic alternatives. The program demonstrated a frequency-agile, lightweight patch antenna for UHF satellite communications that has 20 times less volume than existing antennas and, thus is suitable for low-profile mounting on the roof of military vehicles. We also developed a very low cost, high performance ferroelectric phase shifter for monolithic thin-film electronically steered antenna applications. In fiscal year 2001, the program is expanding its work in electroactive polymers to include the development of thin-film spatial filters that will improve by a factor of 10 the speed and power requirements for sensors for missile defense. In addition, the program is exploring the development and application of artificially engineered nanocomposites or "meta-materials" for achieving electromagnetic properties unobtainable in nature. In fiscal year 2002, the program will demonstrate actuators that mimic biological muscles for robotic applications and meta-materials concepts for a number of important DOD electromagnetic applications. The program will demonstrate a one-megabit, fully radiation-hard memory by the end of fiscal year 2002. This memory will be competitive with conventional memories and will definitely replace some, if not all, of the existing random access semiconductor memories like Flash, Dynamic Random Access Memory (DRAM) and Static Random Access Memory (SRAM). This memory technology is transitioning to the Defense Threat Reduction Agency and the Navy Trident Program, and it is beginning to generate a significant amount of commercial investment.

The Totally Agile Sensor Systems (TASS) program is developing ultra-sensitive radio frequency receivers using high-temperature superconductivity (HTS) filters and low-noise amplifiers. This technology will provide the highest possible sensitivity for communications intelligence and signals intelligence missions pursued by the U.S. military and intelligence communities. The goal is to enable superconducting filters and amplifiers that can achieve up to 10 times the range compared to conventional means for detection of low-level signals. In fiscal year 2000, the program investigated several methods to "tune" the frequency of HTS filters. In fiscal year 2001, the program is working toward tunability of 30 to 50 percent of base frequency demonstrating a system to detect and geolocate sources of unintended radiation for the Rivet Joint aircraft. In fiscal year 2002, the program will push tunability to 100 percent of base frequency, with automatic electronic selection within one millisecond. The program will consider using the technology for non-imaging identification and location of battlefield targets.

Current sensor system architectures sense signals from a physical stimulus, transduce them to electrical signals, convert the electrical signals to digital form for processing by computers, and finally extract critical information from the processed signals for exploitation. Integrated Sensing and Processing (ISP) aims to replace this chain of processes, each optimized separately, with new methods for designing sensor systems that treat the entire system as a single end-to-end process that can be optimized globally. The ISP approach is expected to enable order-of-magnitude performance improvement in detection sensitivity and target classification accuracy, with no change in computational cost, across a wide variety of DOD sensor systems and networks, from surveillance to radar, sonar, optical, and other weapon guidance systems. Fiscal year 2001 was the first year of funding for this program. In fiscal year 2001, the program is developing new mathematical frameworks for global optimization of sensor system performance. In fiscal year 2002, the program will implement physical and software prototypes of the new methodology in test bed systems such as missile guidance and automatic ground target recognition modules for validation and evaluation, and to support continuing iterative development of new design methods for sensor systems.

The Virtual Electromagnetic Test Range (VET) program will develop and demonstrate fast, accurate three-dimensional computational electromagnetic prediction codes enabling practical radar cross-section design of full-size air vehicles with realistic material treatments and details and components such as cavities, thin edges, and embedded antennas. Success will provide the predictive modeling phase of aircraft design with an order of magnitude savings in man-hours; two orders of magnitude reduction in computation expenses may be obtainable. An order of magnitude reduction in range and model costs is also predicted. The biggest impact of these new capabilities is likely to come in the form of cost reductions for modifications and upgrades to existing air vehicles. In fiscal year 2001, the program is developing the capability to predict scattering from deep cavities, gaps, cracks, and thin edges with high fidelity. In fiscal year 2002, it will demonstrate the capability for high fidelity prediction from multi-sensor apertures and arrays.

It has been long recognized that current and future battery technology will not provide sufficient energy to meet the requirements of military missions unless multiple batteries are carried throughout a mission, an incredible expense in logistics and mission effectiveness. This limitation could also significantly degrade the usefulness of emerging systems such as robots and other small unmanned vehicles. To address this issue, DARPA began the Palm Power program in fiscal year 2001 with the goal of developing and demonstrating technologies to reduce the logistics burden for the dismounted soldier by developing novel energy conversion devices operating at 20 watts average power with 10 to 20 times the energy density of batteries. The program is examining several approaches that can convert high-energy-content fuels to electricity, with an emphasis on approaches that can use available military fuels. Among the technologies being considered are: direct oxidation solid oxide fuel cells; extremely compact fuel processors for integration with proton exchange membrane fuel cells; novel small engines; new approaches to solid state thermionic emission and thermoelectrics coupled to advanced miniature combustion systems; and advanced materials and materials processing. In fiscal year 2002, the program will evaluate new materials and concepts to meet program goals.

MEMS

Micro-electromechanical Systems (MEMS) technology enables ultra-miniaturization of mechanical components and their integration with microelectronics while improving performance and enabling new capabilities. The MEMS program has been focusing on developing integrated, micro-assembled, multi-component systems for applications such as aerodynamic control; inertial measurement and guidance; and microfluidic chip-technologies to be used for biological detection, toxin identification, DNA analysis, cellular analysis, drug preparation and drug delivery. Over the last several years, many significant programs were established within DARPA that leverage MEMS technology. One such new activity is the Micro Power Generation program. The development of micro power sources will enable ultra-miniaturization and functionality of new standalone systems. The use of MEMS technology has already demonstrated size reduction, mass reduction, power reduction, performance enhancements, new sensing concepts and new functionality in weapon systems and platforms. Micro power sources will be the key components in ultimate miniaturization and integration of standalone, self-contained, wireless micro-sensors and micro-actuators that can be deployed remotely in clusters to drastically enhance superiority of weapon systems and field awareness. Another new activity is the Nano Mechanical Array Signal Processors (NMASP) program. The development of NMASP will enable ultra-miniaturized (the size of a wristwatch or hearing aid) and ultra low-power UHF communicators/GPS receivers, greatly improving the mobility and location identification of individual warfighters. NMASP technologies will deliver these new component level technologies, as well as new methods for production of mass spectrometers, calorimeters, bolometers, and high-resolution infrared imaging devices.

The objective of the BioFluidic Chips (BioFlips) program is to demonstrate technologies for self-calibrating, reconfigurable, totally integrated bio-fluidic chips with local feedback control of physical and chemical parameters and on-chip, direct interface to sample collection. In fiscal year 2000, its first year, BioFlips identified promising microfabrication platforms to integrate fluidic chip components and developed several subsystem approaches to achieve system specifications. The program used advanced modeling of microscale fluidics to evaluate these subsystem designs. In fiscal year 2001, BioFlips is developing closed-loop bio-fluidic chips to regulate complex cellular and molecular processing through the integration of individual biomolecular transport components and in situ sensors for local feedback control of the fluid parameters. In fiscal year 2002, the program will demonstrate optimization of subsystems and components for integration into prototype systems. Examples of prototype systems include micro flow cytometers that are the size of a wristwatch, a sample preparation microsystem that extracts purified DNA from whole blood samples, and a wristwatch-sized physiological monitor that can acquire body fluids through the skin for measuring blood gas partial pressures, pH, glucose, and hematocrit.

BioFutures (Bio:Info:Micro)

DARPA's investigations at the intersection of biology, information technology and the physical sciences (Bio:Info:Micro) began in fiscal year 2001 with the realization that the biological sciences, when coupled with the traditional strengths of DARPA in materials, information and microelectronics, could provide powerful approaches for addressing many of the most difficult challenges facing DOD in the next 15 to 20 years. Chief among these challenges is preventing human performance from becoming the weakest link on the future battlefield. For example, DOD must be able to maintain the decision-making and fighting capability of the soldier in the face of asymmetric attack (e.g., biological warfare defense), stress and increasingly complex military operations. We will explore and develop new capabilities and methods for performing complex military operations by applying what we learn from the models provided by living systems, which function and survive in a complex environment and adapt, out of necessity, to changes in that environment. In short, the combination of biological science and technology offers an avenue into the understanding—and development for defense applications—of systems that are capable of complex, robust, and adaptive operations using fundamentally unreliable components.

As we proceed with the Bio:Info:Micro initiative, two development themes emerge that have become our organizing principles: critical human factors for future warfighting, and complexity in military operations. The proliferation of technology on the battlefield and the open-market availability of extremely capable weaponry are dramatically shortening the timelines for critical decision-making while increasing the complexity of the battlespace. The tools we develop at the intersection of biology, information technology, and the physical sciences will enable radically new command capabilities to deal with this increased complexity in warfare, while addressing the increasing demands being placed on our warfighters.

Critical Human Factors for Future Warfighting: Human physical and cognitive limitations often constrain technological superiority and superior warfighting, especially in a future battlespace that will continue to increase in complexity and tempo. A major thrust for DARPA's Biological Science and Technology program is to explore solutions to extending human performance. Solutions include extending physical and cognitive performance during the stress of military operation, and interacting with complex, teleoperated, semi-autonomous, and autonomous systems. The program is exploring biological principles and practices to enable new capabilities to sustain or extend human performance for future warfighting. The program will investigate therapeutics, sensors, materials, neural and mechanical interfaces, biological or biomimetic controllers, and learning, memory and training.

Complexity in Military Operations: Military operations and systems are increasing in complexity. DOD must explore new solutions able to maintain superior performance in spite of increased complexity. Living systems demonstrate robust solutions as they operate in a complex world by optimizing performance through adaptive evolution. A major thrust at DARPA will be to explore and develop new capabilities to perform complex military operations based on the principles and practices of biology. Of particular interest to DOD are biological capabilities for: regenerative, cooperative, or redundant processes and materials; information processing; pattern recognition and decision analysis; target identification and acquisition; maneuverability and navigation; stability in wide environmental extremes; and communication of singular or networked systems.

Three programs illustrate DARPA's emphasis on human factors and complexity in military operations:

The Metabolic Engineering for Cellular Stasis program is investigating biological practices that allow organisms to adapt to environmental extremes (water, temperature, salt) and using these practices to engineer new cellular systems such as platelets and red blood cells. In fiscal year 2000, this revolutionary effort demonstrated the functional recovery of dry platelets and other cells that could be used in therapeutic or diagnostic applications for DOD. Future efforts will focus on new engineering methods and practices that result in the enhanced stabilization of cells and tissues.

The Bio-Computation Program is exploring and developing computational methods and models at the bio-molecular and cellular levels for a variety of DOD and national security applications. The program is developing powerful, synthetic computations that can be implemented in bio-substrates, and computer-aided analytical and modeling tools that predict and control cellular processes and systems of living cells. The DOD applications of the program include the ability to predict cellular-level effects of chemical and biological agents and the underlying pathogenic processes; the effect of stress on cell functions (such as circadian rhythms) that affect warfighter performance; and mechanisms for controlling these effects. We are selecting performers in fiscal year 2001. In fiscal year 2002, the program will begin to develop scalable, DNA-based computing and storage and computational models that capture the behavior of mechanisms in living cells underlying pathogenesis and rhythms that are common to many organisms.

The Simulation of Bio-Molecular Microsystems (SIMBIOSYS) program is developing innovative interfaces between molecular-scale processes in chemistry, biology and engineering (electronics, optics, MEMS) through experimental and theoretical analyses. The program is beginning this year by developing experiments, models, phenomenological relationships and scaling laws for a range of bio-molecular recognition processes (i.e., antigen-antibody, DNA hybridization, enzyme-substrate interactions) and bio-fluidic transport processes in microsystems. In fiscal year 2002, SIMBIOSYS will develop methods to transduce these molecular recognition signals into measurable electrical/optical/mechanical signals through integrated on-chip elements that interface with the biological recognition process. We will characterize and quantify innovative transduction (and signal amplification) methods through experiments and models.

Beyond Silicon Complementary Metal Oxide Semiconductors

We are approaching the end of a remarkably successful era in computing—the era in which Moore's Law reigned and where processing power per dollar doubled every year. In large part, this success was a result of advances in complementary metal oxide semiconductor (CMOS)-based integrated circuits. Although we have come to expect, and plan for, the exponential increase in processing power in our everyday lives, today Moore's Law faces imminent challenges both from the physics of deep-submicron CMOS devices and from the enormous costs of next-generation fabrication plants. This situation requires DOD to consider a radically different approach to the fabrication of logic and memories—a program we call Beyond Silicon CMOS.

The Beyond Silicon CMOS thrust is starting in fiscal year 2001. The initiative is aimed at maintaining the phenomenal progress in microelectronics innovation that has served military systems designers so well over the last 30 years. Taking advantage of advanced materials deposition and processing techniques that enable increasing control over material and device structures down to nanoscale dimensions, the Beyond Silicon MOS initiative will enable low-cost-to-manufacture, reliable, fast, and secure information systems critical to meet future military needs. Because the transistors can be made so small, we can make chips with a very large number of transistors per chip, which allows greater fault tolerance and high speed (future microprocessors based on these technologies will run at speeds 10 to 100 times faster than today's best gigahertz-level clock rates). And, with the resulting greater computational power, we will be able to run more complex algorithms to improve security. In the case of the ultimate computers that exploit quantum mechanical effects, we will be able to make use of physical phenomena not available in today's electronic devices to achieve computational capabilities unavailable by traditional techniques.

With a goal to develop new device capabilities, DARPA is exploring options such as non-silicon-based semiconducting materials, including organic and amorphous materials. Components and systems leveraging quantum effects, and innovative approaches to computing designs incorporating these components, will allow low-cost, seamless, "pervasive computing" (making generally available the kind of computing power normally associated with large computing facilities); ultra-fast computing; and sensing and actuation devices. Much as today's desktop computers have the power of the super-computers of a decade or so ago, these chip-scale computers will enable super-computer-like capabilities in portable machines. The military impact could be, for example, to enable a computationally intense synthetic aperture radar capability on a small unmanned air vehicle.

The Beyond Silicon CMOS thrust is composed of five programs that will develop new capabilities from promising information processing components using both inorganic and organic substrates and components and systems leveraging quantum effects and chaos.

The first of the Beyond Silicon CMOS programs is Antimonide Based Compound Semiconductors (ABCS). Its goal is to develop low-power, high-frequency electronics circuits and infrared sources based on the antimonide family of compound semiconductors. Specific goals include circuits with over 104 devices per circuit operating at frequencies above 100 gigahertz and consuming less than one femtowatt (10–12 Joules per second)—a two-order-of-magnitude improvement over today's capabilities (i.e., 10 times faster, consuming one-tenth the power). Specific infrared source goals include operating above thermoelectric-cooled temperatures, with much greater efficiency for continuous wave, mid-wave infrared and single-mode operation in the long-wave infrared range. In fiscal year 2001, this program is demonstrating non-silicon-based transistor technologies and nanostructured materials for quantum-based electronic and optoelectronic device applications. In fiscal year 2002, ABCS substrate technology will accelerate recent breakthroughs in lateral epitaxial over-growth and thin-film delaminating and rebonding to develop a source for ABCS substrates with essentially any desired thermal or electronic property.

Another program is Integrated Mixed Signal Analog/Digital and Electronic/Photonic Systems (NeoCAD) with a goal of developing and demonstrating innovative approaches to computer-aided design of mixed signal (analog/digital) and mixed electronic/photonic systems. The objective is to design and prototype the ultra-complex microsystems having the high degree of integration and complexity needed for military and commercial applications. In fiscal year 2001, NeoCAD is developing fast algorithms for non-linear analysis of mixed signal systems (analog and photonic devices), and the program is extending algorithm methods to non-linear problems. In fiscal year 2002, NeoCAD will develop model order reduction methods (for analog and photonic devices) to enable the creation of device behavioral models, and will develop and demonstrate top-down design capabilities for analog, mixed signal and mixed electronic/photonic systems that match the efficiency currently achieved with digital-only designs.

The goal of the Spins In Semiconductors program is to change the paradigm of electronics from electron charge to electron spin. This can have profound impact on the performance (speed and power dissipation) of memory and logic for computation and for optoelectronics for communications. We can ultimately expect increases in both storage densities and processing speeds of at least 100 to 1000 times. This will give the warfighter the ability to process and assimilate much more data than possible by other means and make him much more situationally aware. Many DOD systems will also benefit from this significantly enhanced performance by enabling much more sophisticated signal processing by allowing our systems to handle significantly more data. For example, if we are successful, we will provide orders of magnitude more flexibility to our remote sensing assets. The program has already demonstrated long-lived electron spin coherence in semiconductors, which translates to very long spin-propagation distances. In fiscal year 2001, we will demonstrate that spin information can propagate across boundaries between different semiconductors in a heterostructure without any loss of spin information. In fiscal year 2002, we intend to demonstrate a very high-speed optical switch using spin precession to control optical polarization.

The Polymorphous Computing Architectures program is developing a revolutionary approach to implementing embedded computing systems that support reactive, multi-mission, multi-sensor, and in-flight retargetable missions and reduce the time needed for payload adaptation, optimization, and verification from years to days to minutes. This program breaks the current development approach of “hardware first and software last” by moving beyond conventional computer hardware and software to flexible, polymorphous computing systems. This program is just beginning and is identifying reactive, in-mission computing requirements and potential polymorphous computing concepts in fiscal year 2001. In fiscal year 2002, the program plans to model and evaluate candidate polymorphous computing architectures.

The Quantum Information Science and Technology (QuIST) program is developing information technology devices and systems that leverage quantum effects and technologies for scalable, reliable, and secure quantum computing and communication. Quantum computers and communication systems are potentially much more capable and secure than today’s systems and can serve DOD’s increasing need for secure communication and computational power to meet the stringent requirements of military data and signal processing. The QuIST program begins this year with investigations of components and architectures of quantum information processing systems, along with algorithms and protocols to be implemented on those systems. In fiscal year 2002, the program will demonstrate techniques for fault-tolerant computation and secure communication, and will demonstrate components of quantum photonic communication systems.

In a revolutionary departure from today’s painstaking circuit fabrication methods, the Molecular-scale Electronics (Moletronics) program is pursuing the construction of circuits using nanoscale components such as molecules and inexpensive chemical self-assembly processes. These chemically assembled systems will have high device density (scaleable to 1011 devices per square centimeter, about 100 times that of current silicon integrated circuits) and low power. It is now realized that requirements for electrical power drive much of the information-age infrastructure, placing ever greater need to obtain low-power electronic systems. In fiscal year 2001, the program demonstrated both the ability to reversibly switch memory molecules at room temperature, the “tools” of computation (“AND,” “OR” and “NOT” gates), and a working 16-bit memory at 10 times the density of silicon Dynamic Random Access Memory (DRAM). In fiscal year 2002 and 2003, we will optimize the performance of the molecular devices, demonstrate a molecular gain device, increase device density, and develop innovative architectures that exploit the unique properties of switching on the molecular scale to demonstrate the advantages of electronics on this scale.

CONCLUSION

Both President Bush and Secretary Rumsfeld continue to highlight the need to take advantage of new possibilities offered by the ongoing technological revolution, as well as to develop defenses against modern technological threats. I hope that this short summary of DARPA's investment strategy has outlined how DARPA stands ready to do both—provide technological opportunities for our warfighters, and harness technology to provide advanced defenses. Our proposed program, of course, will have to change as the nature of the threat changes, and as the strategy for coping with those threats evolves. I thank you for the opportunity to speak with you today, and welcome your questions.

APPENDIX—EXAMPLES OF DARPA'S SCIENCE AND TECHNOLOGY INVESTMENTS IN SUPPORT OF OUR WARFIGHTERS

The Affordable Multi-Missile Manufacturing (AM3) program, a 5-year, DARPA/Tri-Service initiative, was structured to attack rising missile costs with a combination of process and product changes to reduce the cost and cycle times for tactical missile manufacturing. The results are being felt in over 13 military systems, including: a common inertial measurement unit for the Wind Corrected Munitions Dispenser; commercial parts activities for the Low Cost Autonomous Attack System and Army Tactical Missile System; flexible manufacturing systems for Patriot Advanced Capability–3; electronic procurement for Line-of-Sight Anti-Tank weapons; common test approaches for the Evolved Sea Sparrow Missile (ESSM) and Stinger; multi-missile factory approaches for the AIM–9M Sidewinder, the Rolling Airframe Missile, ESSM, Javelin, and BAT brilliant anti-armor submunition; and improved software tool approaches for BAT and the Advanced Precision Kill Weapon System.

The DARPA Compact Lasers program was developed to defend aircraft against heat-seeking missiles. The diode-pumped, mid-infrared, solid-state laser technology developed in the program has been selected to provide the multi-band laser for the Air Force's Phase I Large Aircraft Infrared Countermeasure program. This program's purpose is to protect large aircraft from all currently fielded man-portable heat-seeking missiles. Phase I of the program will outfit large transport aircraft such as the C–17 and the C–130 with defensive systems that use the DARPA-sponsored lasers.

For many airborne systems involving video or infrared sensors, a window protects the sensor from the environment. Flat or gently curved windows can cause drag and other degradations to platform performance. In the Precision Optics program, the window is shaped to meet the needs of the aerodynamic environment, rather than forced to fit commonly used optical shapes for aircraft and missiles. This reduces the aerodynamic drag, which will increase the range or velocity of the missile, and maintains low observability. Precision Optics technologies were demonstrated in an advanced variant of the Stinger missile. This variant of Stinger, like all other electro-optic/infrared guided missiles, had an aerodynamically blunt, hemispherically shaped dome. Using Precision Optics technology, the new seeker head incorporated an ellipsoidal-shaped dome for reduced aerodynamic drag and used correctors to compensate for the look-angle-dependent aberrations. The seeker successfully acquired and tracked targets at Redstone Arsenal, AL. The Army and Navy are conducting development efforts to use the DARPA technology in advanced missiles.

The Moving and Stationary Target Acquisition and Recognition (MSTAR) program has improved advanced automatic target recognition capabilities using the one-foot resolution synthetic aperture radar imagery that is increasingly available from operational platforms. The MSTAR algorithms were evaluated as a component of the Semi-Automated Imagery Intelligence Processor (SAIP) system by replacing SAIP's original automatic target recognition algorithms with the model-based MSTAR algorithms. The MSTAR algorithms have demonstrated correct detection rates of 90 percent or better, and identification rates of detected targets of 80 percent or better. The MSTAR-enhanced SAIP system assists an analyst in forming reports and identifying target types among a set of more than 30 modeled target types. SAIP has transitioned to a Joint Program Office in the Army Space Program Office, which is integrating SAIP capabilities into the operational Tactical Exploitation System.

The GPS Guidance Package (GGP) program has developed a smaller, lower-cost, long-life navigation system based on highly integrated fiber optic gyros, silicon accelerometers, and miniature GPS receivers. The Army is testing the GGP this Spring as an improvement for the Multiple Launch Rocket System firing unit. The adoption of GGP will give the Army the pointing accuracy it needs for its fire support at a fraction of the lifecycle cost of the current Army system.

As U.S. tactical aircraft engage a target, the radars of an adversary's integrated air defense system may track them. DARPA has developed the low-cost Miniature Air-Launched Decoy (MALD) to confuse these defenses. This program achieved its affordability objective, an average unit flyaway price of $30,000 (fiscal year 1995 dollars) if 3000 units are produced. This price is many times lower than currently available air-launched decoys, and MALD's deception performance will be very effective in confusing air defense systems. MALD program management has been successfully transferred to the Air Force, with flight-testing continuing this year. The Air Force is planning a "Silver Bullet" procurement of 100 to 150 MALD units beginning in fiscal year 2002.

In the detection and identification of biological warfare agents, antibody-based sensors have traditionally had difficulty distinguishing between the organism that causes anthrax and other naturally occurring, non-pathogenic relatives within the same genus. Under DARPA sponsorship, researchers have developed a set of antibodies that are highly specific to anthrax, but not to its non-pathogenic relatives. Currently, four of these Anthrax Antibodies are being evaluated by the U.S. Army Chemical and Biological Defense Command (Edgewood Area, Aberdeen Proving Ground, MD) as a possible replacement for the anthrax antibodies in DOD antibody-based sensors. This will decrease the possibility of false alarms caused by cross-reactivity of the antibodies that identify the bioagent.

Another DARPA development is of new antibody-binding reporting material called Upconverting Phosphors (UPTT) for use in sensors for biological warfare agents. Many conventional sensors use fluorescent tags to report the presence of a biological warfare agent as manifested by a binding event taking place (e.g., antibody-to-antigen binding), but the tags have several shortcomings. Fluorescent tags absorb and emit light in similar wavelengths, so signal-to-noise problems limit sensor sensitivity. In addition, only a few separate tags (different fluorescent wavelengths) exist. On the other hand, the UPTT materials are engineered with a novel arrangement of energy states to allow absorption and emission in widely different wavelengths, allowing much greater sensitivity. Also, 18 separate UPTT tags have been developed. The UPTT materials are currently under evaluation by the Joint Program Office-Bio Defense for suitability as a replacement to the fluorescent tags in the currently fielded "Smart Ticket" sensors.

The DARPA Enhanced Consequence Management Planning and Support System (ENCOMPASS) has been transitioned to the Crisis Consequence Management Initiative (CCMI) laboratory located at Space and Naval Warfare Systems Center-San Diego, CA (SSC–SD). CCMI is responsible for other DOD projects that involve aerial surveillance and intelligence support. The CCMI laboratory is currently working in cooperation with Joint Forces Command to install the ENCOMPASS components in support of their mission for Homeland Defense. DARPA's ENCOMPASS investment has led to the development of a commercially available software program for overall resources management for crisis response. Key components of the ENCOMPASS program have been tested at Pacific Warrior and the Air Force Information Warfare BattleLab in San Antonio, TX. In addition, the Air Force's Lightweight Epidemiology Advanced Detection and Emergency Response System (LEADERS) uses key components of ENCOMPASS and will be installed at Wilford Hall Medical Center and Brooks Air Force Base, San Antonio, TX. The Air Force Surgeon General's office is also in the process of installing LEADERS at Air Combat Command, Langley, VA, and Walter Reed Army Medical Center, Washington, DC.

DARPA has helped in the development of a new Navy transition laboratory, the Concept Exploration Laboratory (CXL), that focuses on technology for military medicine. This facility is located at SSC–SD, with experts in operational planning from the Naval Health Research Center and SSC–SD. The CXL vision is to become the focal point for all advanced medical technology for testing and evaluation before prototypes are transitioned to the fleet. CXL is working closely with the Pacific Command to support Cobra Gold in Thailand and the Kernel Blitz Experiment at Camp Pendleton, CA, in June 2001.

The application of fiber-optic technology to high-capacity data-links for electronic warfare, radar and related applications offers a substantial advantage in terms of increased data-handling capability and reduced size and weight over that of existing copper cabling. DARPA's photonics programs have developed technologies for efficient, low-cost manufacturing of optoelectronic components that interface electronic subsystems to fiber cabling. These technologies, such as vertical cavity surface emitting lasers, have resulted in a suite of optoelectronic technologies that are being considered for future insertion into platforms. In particular, the Navy's Fiberoptic Roadmap initiative and the Navy's planned upgrade for the EA–6B aircraft are making use of much of the technology developed in these DARPA photonics programs.

Over the past year, DARPA's Advanced Microelectronics program has demonstrated an impressive array of results in technologies for ultra-short channel transistors, including the fabrication of silicon switching devices with useful electrical characteristics and having the world's shortest channel length (10 nanometers). In addition, this program also demonstrated a fabrication process that uses only conventional equipment to produce transistors with 25 nanometer features (180 nanometers is current state-of-art in production). These short-channel transistors have unconventional device structures but are compatible with ultra large-scale integration into dense integrated circuits. Electrical measurements show that these new transistors are also very fast, attaining switching speeds in the few picoseconds range, thereby enabling future signal processing chips to operate at speeds on the order of 10s of gigahertz. Several other agencies—the National Reconnaissance Office, National Security Agency, and the Defense Threat Reduction Agency—are now collaborating with the AME program contractors to investigate applications of this nanoscale technology.

The Anti-Torpedo Torpedo (ATT) is a new Navy approach to counter-torpedo attack that has significant volume constraints for control electronics. A MEMS-based Torpedo Exploder package offers the required performance in a volume compatible with the ATT design. The exploder incorporates two MEMS devices that have been developed over the past 3 years, a combination flow sensor/accelerometer and an actuator. The MEMS-based ATT has recently undergone two successful sea trials and the Navy has made the decision to continue development. The availability of DARPA's MEMS exploder was one key enabler for this Navy program.

In the area of smart munitions, over the past several years two complimentary DARPA programs have developed MEMS Inertial Measurement Units (IMUs) for use in the guidance package for artillery shells. These MEMS IMUs provide required guidance in a small package capable of withstanding the 50,000 Gs shock experienced when the shell is fired. Following the DARPA demonstration of the capabilities of the MEMS IMU, both the Navy and Army have programmed funds for additional development leading to production.

Senator ROBERTS. Senator Santorum has a 5 o'clock television appearance that he must make, and he would like to make a statement at this point.

Senator SANTORUM. I apologize. I am committed to doing "Hardball." Unfortunately, I did not expect this to go that long. You have been asking too many questions, Mr. Chairman. [Laughter.]

But I want to thank all the panelists, and we have two panelists in the next panel from Pennsylvania, Dr. Kuper and Dr. Gabriel, and I apologize to them for not being able to be here for their testimony. But rest assured, we will submit questions for the record, and I will go over their testimony. I want to thank them for making a special effort to come down and be with us.

I thank all of you as likewise. I appreciate your testimony. This is the beginning from my perspective of a process that is working closely together to make sure that we accomplish the kind of integration that I think is necessary to move our force forward. Thank you all very much.

Thank you, Mr. Chairman.

Senator ROBERTS. Well, again, Senator, you deserve a lot of credit in your leadership in making sure that we had this hearing.

Let me ask each of the Services very quickly, and then we will get to the third panel because it is getting on, transformation efforts, each of you appear now to be focused on preparing the capabilities rather than new systems or platforms.

Briefly tell the subcommittee, if you can, how you determine these future critical capabilities, and then give me two examples if you can of what capabilities that you might envision the U.S. needing in the next 25 years that we do not currently have. [Pause.]

Would you like to make a call? [Laughter.]

Dr. ANDREWS. Let me take a shot at it first. One of the things we do not currently have today for our present platforms that are out there are active protective systems for incoming rounds. So that is a technology that by the end of this decade we should begin to see the first ones built.

Senator ROBERTS. OK. Repeat that for me, please.

Dr. ANDREWS. What we do not have today on platforms—we use steel, yards of steel in front of us to take incoming rounds and live through it. As we go to lighter systems, what we do not have today is an active protection system or a defense system that can knock a missile, or essentially knock it off course before it hits you. So there is an active protection system that is in development in the Army. That should be demonstrated by the end of the decade, for insertion in Future Combat Systems is a good example of that.

Senator ROBERTS. OK. There is one. Any others that you would like to make?

Dr. ANDREWS. Another one possibly is the area of compact kinetic energy missile. We just recently—in the middle of May, we had a demonstration of our line-of-sight anti-tank capability. This is about a 10-foot-tall missile and weighs 200 pounds, travels a mile a second, delivers about six times what the silver bullet of the Army has on a target in terms of energy. It goes through the tank, blows the turret off. We just had a demonstration that this capability works with some critical IMUs.

Since that is such a heavy and large missile, we are in the process right now of developing a compact version of that. Can we have a less than 5-foot version and still deliver nearly equivalent lethality? So by the end of the decade, again, another shot at something significant in terms of lethality. Both survivability for the platform, lethality for the platform, those are two examples.

Senator ROBERTS. Dr. Daniel.

Dr. DANIEL. Thank you, sir. When I look to the future and think about new capabilities, one of the first thoughts that come to my mind is small. Dr. Etter, a few months back, in fact, sponsored a symposium that all of us had the pleasure of speaking at and it emphasized this.

The nanotechnology initiatives that are going on right now, I think have the potential for revolutionizing a broad range of technology as we start using from atomic and molecular building process right on up, particularly in materials as we tailor and scope materials, materials that may be self healing, materials that will sense they need to change or do different functions depending on what situation is going on. So the smallness and nanotechnology revolution, if you will, is something that I am particularly intrigued by.

I am also intrigued by bio sensors. When we look at the many missions the Air Force has, one of the first things we have to do is typically sense what is going on. We have to know what the situation is, what situation awareness is, what an enemy might be doing.

Sensors are the key to doing this. There are many marvelous systems in nature that have effectively electro optic sensors, if you will, that do not require massive amount of cooling. Typically, the kinds of EO systems that we produce do require large amounts of cooling which tend to be very, very heavy, and also tend to be very expensive.

When I look at some of the 6–1 activities we are doing right now, perhaps 100-fold increase of sensor weight might be possible if we could make some of the breakthroughs that I think might be out there in bio sensors. It is an area that does not get a lot of attention, but I think that it has tremendous payoff for us, mission areas that are applicable to all the Services.

So, smallness, nanotechnology revolution, bio sensors, I think, are two great capabilities that we are going to see in the coming decades.

Senator ROBERTS. Admiral.

Admiral COHEN. Mr. Chairman, I think there are a couple—first of all, I believe the Navy is going electric. In fact, the armies of the world are going electric. We are looking very hard at the generation transmission conditioning, stowage, whether it is fuel cells or other means, as well as fascinating propulsion opportunities that this provides. We think we are looking 10 years ahead.

The country is in crisis in energy generation, certainly in some geographic areas, and we think it would be a wonderful time to work together, a long standing history with the Department of Energy to bring to bear some of the technologies that we have invested in.

Another very important area is human factors. We are talking about the DD–21, our future Naval ships, having fewer than 100 in a crew. Every person in the crew might have a college degree, highly trained, bonus, because of the size of the ship and the few numbers in the crew. They might have their own stateroom.

As I say, the Navy version of MREs, meals rejected by Ethiopia—[Laughter.]

But the facts of life are if we do not get that man/machine interface right with time critical strike, more workload on each individual, and a time compressed nature of warfare today, they are not going to stick around. We have all seen people leave and go back to their spouse and say, “I cannot do that one more time.”

Finally, the good news is the Cold War is over, and the bad news is the Cold War is over. The facts of life are the good people of Miramar, Oceania, Langley, and other places just are not going to put up with the sound of freedom much longer; yet we must have a well-trained, combat capable Armed Forces as they sail in harm’s way.

Even though we may not be at war, we have go to figure out how to do that in an environmentally responsible way.

Senator ROBERTS. Doctor.

Dr. ALEXANDER. I think the ability to use legacy platforms and network together to be able to go after time critical targets, both movers and those that are short emitters. We have got a program working called Advanced Tactical Targeting Technology which by using existing communication links ties them together to be able to go within 10 seconds of a time an emitter comes up and take them out.

The second area I would offer is something we are working with Australia on called Metal Storm. It is an electronically ignited gun that is capable of a million rounds a minute, very rapid fire, very controlled. You can do patterns, multiple barrels so you could actually fill space where you need it with projectiles.

Senator ROBERTS. I have some questions that I am going to submit for the record, but in the interest of time I think we are going to get the next panel up. Thank you so much for coming, and for your testimony, for the show and tell which was very interesting, and we look to have you back.

I am going to go ahead and introduce the panel while we are changing the panels.

Panel three has three distinguished researchers involved in the very technologies that have been described as "leap ahead." These researchers are on the cutting edge of today's technological innovation and provide a great service to our Defense Science and Technology Program.

I would like to extend a special welcome to Dr. Peter Sherwood, who is a distinguished professor and head of the Department of Chemistry at Kansas State University, home of the ever-optimistic and fighting Wildcats. Dr. Sherwood has a long career in basic research with carbon fibers, and composite materials. In addition, he is currently the director of the Kansas DEPSCoR. That is the Defense Experimental Program to Stimulate Competitive Research. He is in charge of that program.

This committee has been committed to the DEPSCoR program since its inception back in 1995, and has worked very diligently to increase its budget year over year for the past several years.

The research you do is very important to the S&T enterprise, Dr. Sherwood, even more important to the State of Kansas. We are happy to call you one of our own.

Dr. Kaigham Gabriel is a professor of electrical and computer engineering at The Robotics Institute at Carnegie Mellon University, and will address the subcommittee today on micro electro mechanical systems, MEMS.

Joining him on the panel is Dr. Cynthia Kuper, who is president of the Versilant Nanotechnologies. Is that right?

Dr. KUPER. Versilant.

Senator ROBERTS. Versilant. OK. Thank you. Both of these researchers hale from the great State of Pennsylvania. You have already heard Senator Santorum certainly welcome you to the subcommittee.

I would like to apologize to the panelists. You are like the first responders in our terrorism hearing. By the time we got to the first responders, the people who really do the work, why, most of the crowd left. But I apologize for that.

If we can keep it down to maybe 3 minutes or 5 minutes, I would encourage you to do so. All of your testimony will be made part of the record.

Thank you so much for taking time out of your very valuable schedules to come and share your testimony with us. I know it is a long trip. I know it is taking time out of your schedule, but we welcome you to the subcommittee.

Dr. Sherwood, would you proceed, please?

STATEMENT OF DR. PETER M.A. SHERWOOD, UNIVERSITY DISTINGUISHED PROFESSOR AND HEAD, DEPARTMENT OF CHEMISTRY, KANSAS STATE UNIVERSITY

Dr. SHERWOOD. Chairman, members of the subcommittee, I thank you for the opportunity to submit this testimony regarding the Defense Department's basic scientific research program, the Defense Experimental Program to Stimulate Competitive Research, DEPSCoR, and defense related research in the State of Kansas and at Kansas State University.

I am Peter Sherwood, University Distinguished Professor and Head of the Department of Chemistry at Kansas State University in Manhattan, Kansas. I represent the faculty from the State of Kansas and the Kansas EPSCoR Committee, and I serve as a State of Kansas DEPSCoR Director.

I am here today to speak in support of funding for the Defense Department's basic scientific research program and the DEPSCoR program. This statement is submitted on behalf of the program, the universities pursuing defense related research in the State of Kansas, and Kansas State University.

The DEPSCoR program has led to an increase in regular DOD funding in the State of Kansas. The impact of DOD funding in the state from DEPSCoR and regular DOD grants has been substantial. In my own case, regular DOD funding allowed us to perform detailed studies of the interfacial interactions between a carbon fiber and a matrix with a view to eliminating oxidation in carbon-carbon composites.

Carbon fibers are high modulus fibers that are used to strengthen a matrix to yield advanced composites that are light and strong. The card that you have in your hand, has a tow of 3,000 carbon fibers. If you look very, very closely, you can just resolve a single fiber. That is about 7,000 nanometers. I want to focus on that number because I will talk about an even smaller number in a moment.

These composites are used in stealth aircraft, the U.S. Marine version of the Harrier, and in many commercial aircraft.

The interfacial chemistry has a dramatic effect on the mechanical properties of the composite, and I have studied this interfacial chemistry for many years using the techniques of surface science. The work has enabled us to tailor the surface chemistry of the fiber to optimize interaction with the matrix while reducing or eliminating degradation at the fiber matrix interface.

Many DOD funded projects provide opportunities for basic research of interest to DOD that leads to new developments that can lead to the establishment of local industrial and economic development. For example, at Kansas State University, Dr. Kenneth Klabunde, University Distinguished Professor of Chemistry, has had a long period of continuous DOD regular funding.

This funding enabled him to develop a number of patents related to reactive nanoparticles, tiny particles with dimensions corresponding to an assembly of small numbers of atoms and with remarkable chemical and physical properties. The particles have important military and civilian applications.

You will see a small bottle of a white powder that I have given you. It is about 3 inches long, and contains particles that are only 4 nanometers in diameter. Compare these with the carbon fibers of

7,000 nanometers, where you could just see one of them. The powder particle are only 4 nanometers in diameter. Now these particles that you have in your hand there have a surface area that is about the same as Kansas State's football stadium that seats 50,000 people. This illustrates some of the remarkable properties of this material.

Dr. Klabunde successfully in 1995 developed a company now called Nanoscale Materials, which has been very successful in achieving DOD and other SBIR awards, and together with public funding now employs 20 people and is the first occupant of a research park at Kansas State University.

The focus of Nanoscale Materials has been the use of these nanoparticles for chemical and biological defense applications, destructively absorbing selected chemical and biological warfare agents, rendering them harmless. If you look at that one-page handout, I have a picture of an Anthrax simulant, showing the cell before and after it has been treated with these nanoparticles, which you see have completely destroyed the Anthrax material.

The State of Kansas strongly supports DOD's Science and Technology Programs across all defense organizations, especially those defense research programs providing support to our Nation's universities.

I want to express deep appreciation for the committee's past support of the fiscal year 2001 funding approved for these programs.

I also want to express the appreciation for the committee's past support of the DEPSCoR program which has provided an opportunity for the State of Kansas to construct a program that has enabled the state to promote research of interest to DOD.

This has provided funding from state and other sources, from DOD, to provide $9 million of support over the past 6 years and 26 substantial projects at our three research universities.

The State of Kansas joins many other organizations in urging the subcommittee to increase the Science and Technology Program to $10 billion in fiscal year 2002, a funding target consistent with numerous program and department reviews, including recommendations made by the Defense Science Board. We also respectfully request that you provide $25 million for the DEPSCoR program in fiscal year 2002.

We very much appreciate the opportunities that we have heard of earlier on today that DOD has provided for us to pursue some very exciting research.

Thank you very much.

Senator ROBERTS. Thank you very much.

[The prepared statement of Dr. Sherwood follows:]

PREPARED STATEMENT BY DR. PETER SHERWOOD

Mr. Chairman and members of the subcommittee, I thank you for the opportunity to submit this testimony regarding the Defense Department's basic scientific research program, the Defense Experimental Program to Stimulate Competitive Research (DEPSCoR) and defense related research in the State of Kansas and at Kansas State University.

I am Peter Sherwood, University Distinguished Professor and Head of the Department of Chemistry at Kansas State University in Manhattan, Kansas. I represent the faculty from the State of Kansas and the Kansas EPSCoR Committee, which includes leaders from higher education, state government, and the private sector in Kansas, and I serve as the State of Kansas DEPSCoR Director. I am here today to speak in support of funding for the Defense Department's basic scientific research program and the DEPSCoR program. This statement is submitted on behalf of this program, the universities pursuing defense related research in the State of Kansas and Kansas State University.

The State of Kansas strongly supports DOD's S&T programs across all defense organizations, especially those defense research programs providing support to our Nation's universities. I want to express deep appreciation for the committee's past support and for the fiscal year 2001 funding approved for these programs. I also want to express the appreciation of the committee's past support of the DEPSCoR program which has provided an opportunity for the State of Kansas to construct a program that has enabled the state to promote research of interest to DOD, and has provided support from Federal, State and other sources that has yielded nearly $9 million of support over the past 6 years for 26 substantial projects at our three research universities. We urge the subcommittee to approve robust and stable funding for these basic (6.1), applied (6.2) and advanced technology development (6.3) elements in fiscal year 2002. Specifically, the State of Kansas joins many other organizations in urging the subcommittee to increase the S&T program to $10 billion in fiscal year 2002, a funding target consistent with numerous program and department reviews including recommendations made by the Defense Science Board.

The impact of DOD funding in the state from DEPSCoR and other competitive grants has been substantial. In my own case DOD funding allowed us to perform detailed studies of the interfacial interactions between a carbon fiber and a matrix with a view to eliminating oxidation in carbon-carbon composites. Carbon fibers are high modulus fibers that are used to strengthen a matrix to yield advanced composites that are light and strong. These composites are used in stealth aircraft, in the U.S. Marine version of the Harrier fighter and in many commercial aircraft. The interfacial chemistry has a dramatic effect on the mechanical properties of the composite, and I have studied this interfacial chemistry for many years using the techniques of surface science. This work has enabled us to tailor the surface chemistry of the fiber to optimize interaction with the matrix while reducing or eliminating degradation at the fiber matrix interface.

Many DOD funded projects provide opportunities for basic research of interest to DOD that leads to new developments that can lead to the establishment of local industrial and economic development. For example at Kansas State University, Dr. Kenneth J. Klabunde, University Distinguished Professor of Chemistry, has had a long period of continuous nationally competitive funding from DOD. This funding enabled him to develop a number of patents related to reactive nanoparticles—tiny particles with dimensions corresponding to an assembly of small numbers of atoms and remarkable chemical and physical properties. The particles have important military and civilian applications including air and water purification, environmental remediation and decontamination and industrial catalysis.

Dr. Klabunde successfully developed in 1995 a company to market his inventions, Nanoscale Materials Inc., which has been very successful in achieving DOD and other SBIR awards, together with public funding and now employs more than 20 people and is the first occupant of a new research park at Kansas State University. The company was established with assistance from the Mid-America Commercialization Corporation, a not-for-profit joint venture between Kansas State University, the State of Kansas (via the Kansas Technology Enterprise Corporation), the city of Manhattan and the Manhattan Chamber of Commerce. The focus of Nanoscale Materials Inc. has been the use of these nanoparticles for chemical and biological defense applications, destructively absorbing selected chemical and biological warfare agents, rendering them harmless. Pilot plant production of these nanomaterials has been operational since last year, and has been found effective in the destruction of chemical warfare agents mimics and biological warfare agent mimics (e.g. anthrax simulants, escherichia coli, erwinia herbicola and human virus simulants).

Kansas has responded to concerns about emerging threats and capabilities with new initiatives. A recent initiative from Kansas State University involves a proposed nonlethal environmental evaluation and remediation (NEER) program that uses existing assets in a coordinated manner to form a center (NEERC) to address this challenge. A request for DOD support has been made this year in four areas: nanoparticle responses to chemical/biological threats; a request to develop and manage a Marine Corps urban operations environmental laboratory at NEERC; a request for support of a nanoparticles program for neutralization of facility threats and a smart mortar development and testing program.

I would also like to tell you something about the DEPSCoR program. Based on the positive results of the NSF program, Congress created EPSCoR programs in six additional Federal agencies. One of these is the Defense Department. The individual agency EPSCoR programs, much in the same way as the NSF EPSCoR, help researchers and institutions in participating states to improve the quality of their research so they can compete for non-EPSCoR research funds. The Federal-wide EPSCoR effort funds only merit-based, peer reviewed programs that work to enhance the competitiveness of research institutions and increase the probability of long-term growth of competitive funding.

EPSCoR relies heavily on state involvement and participation, including non-Federal matching funds. Due to the Federal/state partnership upon which EPSCoR relies, and the opportunity that the program provides to allow the states to develop a strategic focus that allows them to enhance their strengths in research, EPSCoR is often considered a model program, and is a wise use of taxpayer funds.

The Defense EPSCoR (DEPSCoR) program contributes to the states' goals of developing and enhancing their research capabilities, while simultaneously supporting the Defense Department's research goals. DEPSCoR grants are based on recommendations from the EPSCoR state committees and the Department's own evaluation and ranking. Research proposals are only funded if they provide the Defense Department with research in areas important to national defense.

Last year the Defense Department issued an announcement of a competition under the aegis of the Defense EPSCoR program. A total of 224 projects were received from the 18 states eligible to participate in DEPSCoR requesting more than $74 million in funding. Following review of the individual projects by the appropriate research office (the Army Research Office, the Ballistic Missile Defense Organization's Science and Technology Directorate, the Office of Naval Research, or the Air Force Office of Scientific Research), 63 projects were selected for funding with $18.7 million made available in fiscal year 2001. The average award was $298,000.

The program in Kansas has had a very important effect on the overall research activities in the state. Twenty-six DEPSCoR projects have been funded in Kansas since the program started in its present form in 1996. The projects were developed by Kansas researchers in collaboration with DOD program managers to address topics critical to defense readiness and capabilities. Before submission of the projects for DOD evaluation, 15 projects were selected from many proposals in a state competition. The state competition involved initial peer review by reviewers outside the EPSCoR states, followed by proposal selection by a panel whose members were also outside EPSCoR states. In this way Kansas researchers were subject to the rigorous national peer review process, as well as benefiting from the valuable feedback provided to the investigator by the review process.

The program is a true partnership between DOD, the State of Kansas, and the three research universities in the state. Funding to date has involved nearly $9 million with about 56 percent of the funding coming from DEPSCoR, 28 percent from the State of Kansas and 16 percent from the universities involved. Faculty of all ranks have been involved, with the senior faculty providing a mentoring role. DEPSCoR projects have improved the Kansas infrastructure for defense related research; about half the projects have been in engineering and the other half in physics, chemistry and mathematics.

I will now discuss two projects from the twenty-six funded projects to illustrate the impact that these grants have had in yielding research results that benefit our Nation's defense, that improve the ability of Kansas to perform defense related research, and that have enabled faculty to become more competitive, and in the case of younger faculty to launch their research careers. Fifty percent of the DEPSCoR projects have been located at Kansas State University, and the remainder at the University of Kansas and Wichita State University.

An Assistant (now Associate) Professor of Physics at the University of Kansas, Dr. Judy Wu, has developed methods for coating mercury-based high temperature superconductors onto oxides and metals in processes that have led to two United States patents, and one U.S. patent pending. Superconducting coatings of these materials, that have transition temperatures above 130K onto oxides, can be used for superconducting microwave telecommunication devices of superior performance in terms of low loss, high resolution, and light weight. These properties have recently been demonstrated on small-scale microwave devices. Superconducting coatings of these superconductors onto metals can be used to form superconducting cables that can be used for power-related applications including low-loss/high power generators, transmission cables, electric motors, and high-field magnets. Dr. Wu now has nationally competitive DOD funding.

Dr. Ramesh Agarwal, Bloomfield Distinguished Professor of Aeronautical Engineering led a project with Dr. M. Papadakis, Associate (now Full) Professor of Aeronautical Engineering at Wichita State University. The project was concerned with the development of computational electromagnetics for solving scattering, radiation and electromagnetic environmental problems of considerable importance to DOD. These workers developed a higher-order Discontinuous Galerkin (DG) finite-element method for the solution of the Maxwell equations on structured grids. The method proved very accurate, and much more efficient than existing formulations, and has allowed for the accurate computation of electromagnetic scattering. The approach will have a significant payoff for three-dimensional studies that will assist the development of stealth aircraft and missile systems. The project provides an example of the leadership and mentoring by senior faculty that is an important component in the success of the DEPSCoR program.

Kansas continues to seek support through regular DOD programs and through the DEPSCoR program that will enable the State to play its part in the national contribution to DOD programs and interests. The State strives to make its university faculty aware of DOD programs, encouraging contacts and visits with DOD program managers. New faculty are encouraged to develop new programs of interest to DOD, and established faculty play a key mentoring role for such faculty as well as conducting their own DOD supported programs. The challenges of large collaborative programs are being actively pursued, as well as the opportunities for economic development through spin-off technology.

The State of Kansas appreciates this subcommittee's long-standing support for Defense EPSCoR and we urge you to continue that support. The State recognizes the very tight fiscal constraints this subcommittee faces in the new era of a balanced Federal budget, but we respectfully request that you provide $25 million for the Defense EPSCoR program for fiscal year 2002.

The Defense Department's Experimental Program to Stimulate Competitive Research is a wise and worthwhile investment of scarce public resources. It will continue to contribute significantly to efforts to build scientific and engineering research efforts in support of national defense needs.

Mr. Chairman, the State of Kansas strongly supports the Defense Department's basic research programs (functions 6.1 and 6.2). With the end of the Cold War, the technological demands facing our military have increased. New research must be pursued to meet new challenges in the fields of information warfare, high technology terrorism, the proliferation of weapons of mass destruction and threats in diverse parts of the world.

It is essential that Congress ensure that scientific research and technological advances in support of our military are not eroded because of the lack of adequate funding for DOD's 6.1 basic and 6.2 applied research. We have joined with our colleagues in the research community to urge the administration and Congress to strengthen the Nation's investment in the Department of Defense's (DOD) Science and Technology (S&T) programs. These programs are vital to our Nation's security and technological superiority. We strongly endorse recommendations that Congress to provide $10 billion for DOD S&T programs for fiscal year 2002.

Thank you for your consideration of this request.

Senator ROBERTS. Now I am going to ask you what I asked Carolyn Hanna of the committee staff. Carolyn back here says that it would take her too long to explain it to me. [Laughter.]

Then I asked Alan McCurry of my staff to explain it to me, and he said he understands it. This half-filled tube contains magnesium oxide nanoparticles that are only four nano—nano-what?

Dr. SHERWOOD. Nanometers.

Senator ROBERTS. Nanometers in diameter. These particles have a surface area—do you mean the total in the——

Dr. SHERWOOD. In that tube.

Senator ROBERTS. In that tube, equal to that of the football stadium at Kansas State——

Dr. SHERWOOD. That is right.

Senator ROBERTS. —and you have got a picture of the stadium. I think I can see myself down there. [Laughter.]

I do not understand that. Do you mean that that surface particle of all these little guys here is equal to that of the entire stadium? Is that right?

Dr. SHERWOOD. That is correct. That is correct. It is due to the many different facets that one sees on those materials.

One example I might give you is if you look at the United Kingdom which has an area comparable to that of the State of Kansas, if you walk along the state boundaries of the State of Kansas, because the boundaries are fairly straight, you will cover a certain number of miles.

If you walk around the boundaries of the United Kingdom which is about the same area, you will have covered something like a hundred times the distance covered on the Kansas trip simply because the United Kingdom is so indented with little creeks, and——

Senator ROBERTS. I see what you are saying.

Dr. SHERWOOD. It is the same idea with those nanoparticles.

Senator ROBERTS. That is amazing. Dr. Gabriel.

STATEMENT OF DR. KAIGHAM J. GABRIEL, PROFESSOR, ELECTRICAL AND COMPUTER ENGINEERING, THE ROBOTICS INSTITUTE, CARNEGIE MELLON UNIVERSITY

Dr. GABRIEL. Thank you, Mr. Chairman, distinguished members of the subcommittee.

The points I would like to make today are based on two decades of research experience at MIT, Bell Labs, and Carnegie Mellon University. In addition to the academic and industry experience, I served for 6 years at DARPA culminating in a Senior Executive Service position as the director of the Electronics Technology office where I was responsible for annual research and development budget of $400 million.

Since the end of the Cold War, the technology landscape has changed, and that change is accelerating. The technology landscape over the next two decades is going to be different from the technology landscape of the last two decades in some very fundamental ways.

One is that the advances of these technologies are being primarily driven by the commercial interests. Two, the technologies that are militarily relevant are changing and increasing in number; just as an example, we heard from the previous panel, biotechnology and bio sensors coming up when I think you would not have heard that 10 or 15 years ago from the DOD.

Three, the rate of change in those technology areas is increasing, and the new capabilities, the "leap ahead" capabilities that we all are focusing on here today, are happening at the intersections of different technology areas.

Finally, something that was coming up quite a bit in both the first and second panels, it is not only the process of who is going to develop these technologies first that is going to be a determinant, but who is going to be good at using them and experimenting, and putting them into systems and use that is also going to be determining the military capabilities.

One recent example of technology intersections yielding these "leap ahead" quantum jumps and capabilities is in the area of microsystems being integrated with biotechnology. Drug discovery is being done 100 to 1,000 times faster today because of this integration of MEMS and biotechnology. Chips that are no larger than a postage stamp using thousands of micro wells make it possible for researchers to test thousands of different drug combinations all at the same time.

Further advances in this sort of integration will lead to real-time fuelable systems that will detect, identify chemical and biological agents allowing for rapid response for protection of forces and for homeland defense.

A second example of this technology integration coming together is a chip that I brought here which I would be happy to show you or send up, which integrates which is—this chip is no larger than a pin head. [Indicating] We can put a microscope on top of it so you can see it.

It has an integrated membrane that can vibrate to hear sounds. It is made like any other microchip, and can be integrated with electronics, and could cost less than 50 cents each so that hundreds of thousands could be deployed so that—like grains of the sands, and it would give adversaries no place to hide. This technology is a direct result of MEMS, a technology that was advanced and applied because of research as we heard from the development funding from DARPA.

Over the past decade, MEMS technology has led to accelerometer and gyroscope chips, as you saw from Dr. Alexander's presentation. Over the next decade, we believe that MEMS will create belt-buckle-size inertial guidance systems, optical switches and filters, and complete chemical and biological factors on a chip.

While funding for basic research is really important at the intersections of technology, it is also important so that DOD can provide a focusing for this research for well-defined "leap ahead" capabilities.

A Defense Science Board study, which I had the honor of chairing a few years back, came up with a couple of key technologies for the defense capabilities over the next 15 to 25 years. Those technologies were not a surprise, biotechnology, information technology, microsystems, and materials and energy. We heard those before from the previous panels.

What was new was two very important recommendations from that panel: One, focusing investments on the intersections of technologies which is where the quantum capabilities and performance are going to come from; and, two, was focusing much of the research and basic research for capability driven, grand challenge, "leap ahead" capabilities.

With those sort of investments, such technology investments, driven by the DOD, we can ensure the offensive and defensive U.S. military capabilities will continue to be unique and overwhelming as we have been before.

With such investments—without such investments, we risk failure. With such investments, we cannot fail to succeed.

Thank you, Mr. Chairman.

Senator ROBERTS. Thank you, Dr. Gabriel.

[The prepared statement of Dr. Gabriel follows:]

PREPARED STATEMENT BY DR. K.J. GABRIEL

Mr. Chairman and distinguished members of the subcommittee. Thank you very much for the opportunity to provide testimony on "leap-ahead" technologies and transformation initiatives within the defense science and technology programs.

The points I'd like to make today are based on over two decades of research experience that I have had at MIT, AT&T Bell Labs and Carnegie Mellon University. In addition to my academic and industry experience, I served for 6 years at DARPA, culminating in a Senior Executive Service position as Director of the Electronics Technology Office responsible for an annual research and development budget of more than $400 million. Most recently I co-chaired the Defense Science Board Summer Study Task Force on Defense Technology Strategy, Management and Acquisition.

Since the end of World War II, technology advances have provided new, unique, and overwhelming capabilities for the military forces of the United States. These advances were often focused on DOD-unique objectives and interests, and typically developed by defense-sector industries.

For the past 40 years, the technologies of military relevance have been aerospace, nuclear, electronics, missile and marine/undersea technologies. For those technologies, development and evolution cycles were measured in years and decades, and the technologies were difficult and costly for our adversaries to develop or acquire.

As a Nation we've been served well by these past research and technology investments In recent conflicts, capabilities derived from these technologies have given the U.S. superior advantages including: precision-guided munitions; "owning the night" with night vision capability; and stealthy aircraft, weapons, and ships.

Since the end of the Cold War, however, the technology landscape has changed—and the change is accelerating.

The technology landscape for the next two decades differs from the technology landscape of the last two decades in five fundamental ways:

1. Advances in most technologies will be driven primarily by commercial interests;
2. The types of technologies that are militarily relevant are changing and increasing in number;
3. The pace of advance in those technology areas that have military relevance is increasing; and
4. New capabilities and quantum jumps in old capabilities are increasingly occurring at the intersections of different technologies; and
5. Turning technologies into capabilities is governed not only by who develops better technologies first, but equally by who has the better process of experimenting with and integrating technologies into systems.

If the DOD does not navigate this new technology landscape successfully, it is in danger. It is in danger of losing old capabilities and of not being able to acquire new offensive and defensive capabilities quickly enough. More significantly, the new technology landscape leaves the DOD vulnerable to those new capabilities being acquired first by others.

Not only are new technologies needed to meet the need of the coming decades, but the DOD needs new ways of focusing, funding, developing, and using those technologies.

The 1999 Defense Science Board Study identified key DOD technology areas and research funding strategies to enable order of magnitude improvements in military capabilities over the next 10 to 25 years. The key research areas identified were not a surprise nor were they new. The areas are: biotechnology; information technology; microsystems; and materials and energy.

What is new are two recommendations for where and how DOD funding should be directed in those areas: first, the call for DOD to focus and allocate significant fractions of basic research funding at the intersections of these technologies; and second, the call for DOD to allocate significant portions of basic research funding toward objectives that translate to clear and revolutionary capabilities. It is at the intersections of technologies where quantum jumps in capabilities are realized. It is when we have clear objectives that productive and useful capabilities are developed.

One recent example of technology intersections yielding quantum jumps in capability is in drug discovery. Drug discovery is beginning to be done 100 to 1000 times faster than before because of microsystems being integrated with biotechnology. Chips no larger than a postage stamp with thousands of micro wells and channels enable researchers to assess the efficacy of thousands of different combinations of chemicals as a drug—-all at the same time.

We believe further advances and integration with information technology will lead to real-time, in-the-field systems that will detect and identify chemical and biological agents, allowing rapid response for the protection of deployed forces as well as for homeland defense.

A second example is a chip that I have brought here with me today. It is a microchip the size of a pinhead with an integrated membrane that can either hear sounds or vibrate to produce sounds that you can hear. It is a direct result of

MEMS—micro electro mechanical systems, a technology that was advanced and applied because of research and development funding from DARPA.

MEMS technology makes it possible to build microscopic mechanical components on the same chip with electronics, using the materials and processes of microelectronics fabrication. Over the past decade, MEMS technology has led to: accelerometer and gyroscope chips, and high-resolution, large area displays using arrays of millions of micromirrors-—with each mirror the size of blood cells.

Over the next decade, we believe MEMS Microsystems technology, coupled with other technologies, will lead to belt-buckle-sized inertial navigation systems, optical switches and filters for fiber-optic telecommunications systems, and complete chemical and biological laboratories on a chip.

While funding basic research at the intersections of technologies is important, it's also important for the DOD to focus research by articulating far-reaching but well-defined objectives in capability.

Too often the argument is made that since the ultimate utility of basic research is hard to predict, basic research should be completely unfettered-free to roam where it may. I believe otherwise.

The history of scientific and technical advance is filled with dead ends, lucky short cuts, and unanticipated vistas. But unstated in most of this history is that people were originally trying to get somewhere. They had an objective. They just didn't know exactly how they were going to get there or when. Many times where they wound up turned out to be more important than where they were originally going. Having an objective allows researchers to gauge their progress and make reasoned choices about pursuing certain avenues while abandoning others.

We recently celebrated the 50 anniversary of the ENIAC (Electronic Numerical Integrator And Computer), the first general purpose electronic computer built using DOD research funds at the University of Pennsylvania. The ENIAC was not built because the DOD saw the Internet coming, but neither were precious Federal monies spent to build the computer just because it would be interesting. The DOD funded the ENIAC because it needed a faster and more efficient way to update artillery ranging tables.

The basic research funded at the University of Pennsylvania had an objective and in the course of meeting that specific objective, we uncovered the new, rich and exciting vista of information technology.

Universities have been and will continue to be the source of such new technologies. Just as importantly, universities continue to be the source of people skilled in the development and use of new technologies. With the passage of the Bayh-Dole act of 1980 universities have also become and are increasingly the source of technology transfer and commercialization for emerging and new technologies.

The DOD has an opportunity. The DOD needs to continue and increase its funding of basic research. But it's not enough to simply add more money to traditional approaches. We need to recognize the changes in the technology landscape and adapt our funding strategy continuously to meet new challenges and take advantage of new opportunities. The DOD, with its mission orientation, is unique in its ability to focus on capabilities and influence the course of technological advance, particularly in the early, basic research stages of technology developments.

The DOD can focus, harness and accelerate developments of new leap-ahead technologies at the intersection of traditional disciplines. Such technology developments, focused on and driven by far-reaching DOD needs, will help insure that the offensive and defensive U.S. military capabilities will continue to be unique and overwhelming. Without such investments, we are sure to fail. With such investments, we cannot fail to succeed.

Mr. Chairman this completes my remarks. I would be happy to answer any questions the subcommittee might have.

Senator ROBERTS. Dr. Kuper.

STATEMENT OF DR. CYNTHIA A. KUPER, PRESIDENT, VERSILANT NANOTECHNOLOGIES

Dr. KUPER. Thank you, Mr. Chairman and the subcommittee, for giving me this opportunity to speak with you today regarding the present status and future direction of nanotechnology. I prepared a written statement, and I wish to read excerpts from that.

Senator ROBERTS. Certainly.

Dr. KUPER. If I were asked to testify before you just a few years ago, I would have used words like "imagine" and "potential."

Today, I use words "will" and "can." I am here to tell you where nanotechnology is and where it is going.

Nanotechnology is the technology of science on the nano scale, the size scale of atoms and molecules, one billionth of one meter. It is the most powerful form of engineering we know of and thus brings with it the most innovative and revolutionary materials that exist in the universe.

Nanotechnology holds the key to our future, a future that began over the last decade in university laboratories across our country and the world, where scientists embarked on studies of new forms of carbon that is 100 times stronger than steel and weighs 1/6th as much, wires made out of single molecules and pathways to engineer devices half the size of the diameter of a human hair.

The future of these findings will lead to desktop computers the size of credit cards, vehicles for land and air that self-heal and think, and multi-functional materials. An example of a multi-functional material that would greatly benefit soldier land warfare is a jacket worn by a soldier that weighs as much as a cotton shirt, but yet is a ballistic shield, a portable power supply, and a medicine cabinet of anti-biological warfare agents, holding the vaccines in tiny capsules ready to release them when its sensors detect their presence in the air.

In this future we will use a new form of carbon to deliver drugs to infected cells, and conversely use the bacteria that infected the cells to build computers. The use of bacteria for molecular circuitry has already been demonstrated.

I am fortunate to have worked with these materials first-hand and am humbled to say that I have been trained by some of the world leaders in this field. I began my scientific endeavors in the laboratory at the age of 15, working on cures for breast cancer. I obtained my doctorate in Chemistry and never dreamed I would be on an adventure such as this one, having the opportunity to work with Nobel laureates and our space agency to develop these materials, and to obtain a glimpse into our future.

Nanotechnology will build a new class of air and spacecraft using materials with the highest strength-to-weight ration ever seen. These materials are called carbon nanotubes. Their diameter is one billionth of one meter; that is 10,000 times smaller than the diameter of the human hair. Their lengths are a micron, one millionth of one meter.

These are single molecules and, therefore, they are without defect. Their unique structures give them strengths 100 times greater than steel and 1/6th the weight of steel, half the weight of carbon fibers used today.

High strength and low weight is just the beginning of the remarkable properties of these materials. They also conduct electricity equal to copper without the loss of heat. Carbon nanotubes have extremely high thermal conductivities as well, and are unreactive in most environments. Each desired physical property is obtained simply by rotating the molecule from 0 to 90 degrees.

With carbon nanotubes we can build maritime vehicles that evade corrosion and detection by the enemy. We can build airplanes with warping wings that respond automatically to environmental conditions and that are lighter and more fuel-efficient. We can build computer circuits orders of magnitude smaller than today's standards. We can build our future, a future that looks as perfect as the nature that surrounds us.

I look toward the government for strategic investment in nanotechnology similar to its investments during the 1950s, which led to micro technology, micro fabrication, and the computer technology of today. This was our past. It has been fruitful and formidable, but has run its course.

The technology of the past cannot answer our needs for today and our needs for the future. We need lighter and more fuel-efficient vehicles. We need better forms of power storage. We need orders of magnitude increase in data storage capabilities. We need our soldiers better protected on the battlefield.

The lead-time for a science to become technology is 10 to 15 years. We have just passed a decade in nanotechnology, and this is a most critical time. We must take nanotechnology out of the laboratories and into the market. We must move from characterization to fabrication. We must build, and we must invest.

Once it was thought that the largest barrier to our technology of the future was the technology itself, not having microscopes powerful enough to see individual atoms and molecules, not understanding the physics and chemistry of the size scale. The scientific community has overcome these obstacles and surpassed them.

Today without question the largest barrier to taking the next step is economic. The materials of nanotechnology are ready to be fabricated into useful forms so that the military and society can realize their extraordinary benefits. We are ready to break away from basic science and become an applied industry. This is evidenced by the number of new nanotechnologies startup companies growing every day.

Now I will use the word "potential." These small businesses have the potential to supply the material to the military needed to build the next generation of defense products. These businesses need an infrastructure to survive. They need investment, and they need goals.

The Defense Department will greatly benefit by forming strategic partnerships with the nanotechnology private sector. Department of Defense appropriations can bring speed to market so that the military can reap the benefits.

Senator Santorum has shown great vision in this area, realizing that nanotechnology will facilitate the development of unmanned air and land vehicles and greatly improve ballistic shielding. It is time to bring that vision to fruition.

I urge the Senate to make a small investment which promises to reap enormous rewards. Thank you.

[The prepared statement of Dr. Kuper follows:]

PREPARED STATEMENT BY DR. CYNTHIA KUPER

Senator Roberts, and members of the subcommittee, I greatly appreciate the opportunity to speak with you today regarding the present status and future direction of nanotechnology.

If I were asked to testify before you just a few years ago I would have used words like "imagine" and "potential." Today I use the words "will" and "can." I am here to tell you where nanotechnology is and where it is going.

Nanotechnology is the technology of science on the nano scale, the size scale of atoms and molecules, one billionth of one meter. It is the most powerful form of engineering we know of and thus, brings with it the most innovative and revolutionary materials that exist in the universe.

Nanotechnology holds the key to our future, a future that began over the last decade in university laboratories, across our country and the world, where scientists embarked on studies of a new form of carbon that is 100 time stronger than steel and weighs 1/6 as much, wires made out single molecules and pathways to engineer devices half the size of the diameter of a human hair. The future of these findings will lead to desk top computers the size of credit cards, vehicles for land and air that self-heal and think, and multi-functional materials. Such an example of a multi-functional device that will greatly benefit soldier land warfare is a jacket worn by a soldier that weighs as much as a cotton shirt, yet is a ballistic shield, portable power supply, and a medicine cabinet of anti-biological warfare agents, holding the vaccines in tiny capsules ready to release them when its sensors detect their presence in the air. In this future we will use carbon nanotubes to deliver drugs to infected cells and conversely use the bacteria that infects cells to build computers. The use of bacteria for molecular circuitry has already been demonstrated.

I am fortunate to have worked with these materials first-hand and am humbled to say that I have been trained by some of the world leaders in this field. I began my scientific endeavors in the laboratory at the age of 15, working on cures for breast cancer. I obtained my doctorate in Chemistry and never dreamed I would be on an adventure such as this one; having the opportunity to work with Noble laureates and our space agency to develop these materials, to have a glimpse into our future.

Nanotechnology will build a new class of air and spacecraft using materials with the highest strength-to-weight ratio ever seen. These materials are called carbon nanotubes. To visualize a carbon nanotube, visualize a sheet of chicken wire and place a carbon atom in every vertice in the chicken wire. Then roll up the sheet so that is closes upon it self at the edges seamlessly. You have just formed a long tube made solely of carbon atoms. Now, if you will, envision a soccer ball. Place a carbon atom in every vertice on the stitching of the soccer ball. This is a carbon 60 molecule, or Bucky ball, named after the architect Buckminster Fuller.

Take this soccer ball and cut it in half. Use each half to cap the ends of the long tube. This is a single-wall carbon nanotube. Its diameter is one billionth of meter and its length is a micron, one millionth of one meter. These are single molecules and they are with out defect. Their unique structure gives them strengths 100 times greater than steel and weight 1/6 of steel, 1/2 as much as carbon fibers used today. High strength and low weight is just the beginning of the remarkable properties of these materials. They also conduct electricity equal to copper without the loss of heat. Carbon nanotubes have extremely high thermal conductivities as well and are unreactive in most environments. Each desired physical property is obtained simply by rotating the molecule from 0 to 90 degrees. With carbon nanotubes we can build maritime vehicles that evade corrosion and detection by the enemy. We can build airplanes with warping wings that respond automatically to environmental conditions and that are lighter and more fuel-efficient. We can build computer circuits orders of magnitude smaller than today's standards. We can build our future, a future that looks as perfect as the nature that surrounds us.

I look toward the government for strategic investment in nanotechnology similar to its investments during the 1950's, which led to micro technology, micro fabrication and computer technology. This was our past. It has been fruitful and formidable, but it has run its course. Technology of the past cannot answer our needs for today and the future. We need lighter more fuel-efficient vehicles. We need better forms of power storage. We need orders of magnitude increase in data storage capabilities. We need our soldiers better protected on the battlefield. The lead-time for a science to become a technology is 10–15 years. We have just passed a decade in nanotechnology. Now is a critical time.

The future is today. The question is no longer how. The question is when. We must take nanotechnology out of the laboratories and into the market. We must move from characterization to fabrication. We must build. We must invest.

Once it was thought that our largest barrier to the technology of the future was the technology itself, not having microscopes powerful enough to see individual atoms and molecules, not understanding the physics and chemistry at this size scale. The scientific community has overcome these obstacles and surpassed them. Today without question the largest barrier to taking the next step is economic. The materials of nanotechnology are ready to be fabricated into useful forms so that the military and society can realize their extraordinary benefits. We are ready to break away from basic science and become an applied industry. This is evidenced by the number of new nanotechnology start up companies growing everyday.

Now I will use the word "potential." These small businesses have the potential to supply the military with materiel needed to build the next generation of defense products. These businesses need an infrastructure to survive. They need investment and goals. The defense department will greatly benefit by forming strategic partnerships with the nanotechnology private sector. Department of defense appropriations can bring speed to market so that the military can reap benefits.

Senator Santorum has shown great vision in this area, realizing that nanotechnology will help to make unmanned air and land vehicles a reality and greatly improve ballistic shielding. It is time to bring that vision to fruition. I urge the Senate to make a small investment, which promises to reap enormous rewards.

Senator ROBERTS. Dr. Kuper, you mentioned in your written testimony that you just finished, the Department of Defense will benefit by forming a strategic partnership with industry such as yours. How would you characterize the ease with which small businesses can work with the Department of Defense so that your "will" and "can" banner can be raised high?

Dr. KUPER. Well, my past experience has been that the ease has been easy. We have worked with NASA successfully. I think that there would be a great deal of ease with which the Department of Defense could work with the private sector, especially in the materials concentration of nanotechnology, because the commercial interest and the military interest overlap so much.

I look back to the Star Wars Program and wonder if one could not take that decade and compress it into yearly cycles of military advantage and products that come into the commercial sector.

Most of the people that live in the United States today, do not realize many of the products that came out of the Star Wars Program that they use every day. I do not even know if researchers know how much it benefited our analytical equipment and characterization that we use, which came out of that program so many years ago, which also benefited and strengthened the Department of Defense.

My vision would be to implement such a program with nanotechnology to make strategic investments in small business that have these material capabilities. These companies that would be invested in would have short-term commercial viability, and also suit the immediate needs of the Department of Defense.

Senator ROBERTS. So you are saying here on your second page, "Technology of the past cannot answer our needs for today and the future. We need lighter, more fuel-efficient vehicles."

I just went to many town hall meetings in Johnson County in Kansas. That is the place where everybody who works in Kansas City would like to live, and we had about 250 in each town hall meeting. I asked how many people would be willing to go the speed limit of 55 with a much more smaller vehicle, et cetera, et cetera. A lot raised their hand, and a lot did not.

"We need better forms of power storage. We need orders of magnitude increase in data storage capabilities." Then you switched, like you are stating here and say, "We need our soldiers better protected on the battlefield." So, this is not an either/or thing. There is a direct benefit that when you invest in the technology for one, you get the other, right?

Dr. KUPER. Yes, I do believe that.

Senator ROBERTS. You say, "That is a technology of 10 to 15 years. We just passed a decade. Now is a critical time."

Not a problem with the research and the chemistry, it is a problem with economics, is that correct?

Dr. KUPER. Yes.

Senator ROBERTS. You were 15 when you began your scientific endeavors in the lab?

Dr. KUPER. Yes, that is correct.

Senator ROBERTS. Let me ask you an un-PC question. [Laughter.] How old are you now?

Dr. KUPER. I will be 29 next month.

Senator ROBERTS. I see. Thank you for your testimony.

Dr. KUPER. Thank you, Mr. Chairman.

Senator ROBERTS. Dr. Sherwood, in your written statement, you have a proposed initiative that I am certainly involved with in regards to what we call a "non-lethal environmental evaluation and remediation program" at Kansas State. You have four areas that could really be of importance to the war factor. Do you want to go over those real quick, if you can?

Dr. SHERWOOD. Yes. I am not personally directly involved in this program, but I can tell you that many of these involve the nano materials of the sort that I have given you today. What Kansas State is trying to do, and I think is a very good example of what is happening in this area which is to optimize the approach by bringing together all of the talents that are present at the moment in the university, and bringing together people who have not previously been involved.

The catalyst for this, the engines to make this possible, is this new approach in nano materials, and this has brought partnerships that previously have not been in place. One will see this as a partnership between scientists, engineers, agricultural experimenters, and so on.

Senator ROBERTS. Dr. Gabriel, you mentioned that basic research is hard to predict and many believe it should be completely unfettered. But you disagree with this—this seems to be somewhat of a unique opinion. Could you elaborate on the need for the Department of Defense to focus on far future capabilities in its basic research?

Dr. GABRIEL. Thank you. Before I answer that, I want to just quickly point out, I failed to mention that if you press the button on the side of the thing that went up, you can see the membrane actually deflect, for later amusement.

The answer to the question about objectives: I think many times there is a perception that the freer you are in being allowed to be completely undirected, that the more productive it can be. The history is filled with—history of technology advances is filled with shortcuts, unforeseen opportunities that people take up, and many times, they wind up in places which are even more important than when they originally started out going.

As an example of that in my written testimony, I pointed out we recently celebrated the 50th anniversary of ENIAC which was built by Defense Department funding, basic research funding, at the University of Pennsylvania in 1946. Now ENIAC was the first electronic computing device, filled a room roughly this size.

It was not done because the Army or the Department of Defense foresaw the Internet, but neither was it done just because it was something that would be interesting to do. It was done because the Army needed more efficient and faster ways of generating artillery tables, calculation tables. Now in the process of reaching that objection, we, of course, uncovered this whole rich new area which we are still uncovering of information technology.

That is the sense in which I think it is important to have a far reaching objective. It is not a prescription. It is not a direct that "You will do this. You will do this. You will do this." But it is a target which is really stretching everyone's capabilities, stretching the technologies, stretching our ability to produce it that will really generate the productive research that we need.

Senator ROBERTS. So there is a focus.

Dr. GABRIEL. A focus, exactly.

Senator ROBERTS. There is at least some direction, some kind of a mission that you are trying to accomplish as opposed to just basic research.

Dr. GABRIEL. Exactly.

Senator ROBERTS. I do not mean "just basic" research. I remember back in my House days when I was Chairman of the Agriculture Committee, and prior to that, and we would always get into the debate of applied and basic research. Very few members of Congress appreciate the need for basic research. They want to touch it and feel it, more especially if it is in their district. [Laughter.]

In most cases, if it did not end up in Mr. Whitten's district in Mississippi, why, it did not get funded. Now that is probably an overstatement to say the least, but that is interesting.

I think that in the interest of time and get you on your way, we are going to end the hearing. But I want to thank you so much for your time and effort and for your testimony and for coming down today.

Rest assured, this subcommittee will continue to make that investment that Dr. Kuper was talking about in science and technology because it is our future. Thank you so much for coming.

This subcommittee hearing is adjourned.

[Questions for the record with answers supplied follow:]

QUESTIONS SUBMITTED BY SENATOR PAT ROBERTS

TECHNOLOGY READINESS LEVELS (TRLS)

1. Senator ROBERTS. Dr. Andrews, Dr. Daniel, Dr. Alexander, and Admiral Cohen, there has been increasing interest in "best business practices" in the technology development and insertion arena. I understand that the Department of Defense has adopted using Technology Readiness Levels as a communications device between the S&T and acquisition communities. Could you comment on the acceptance or utilization of Technology Readiness Levels by your service/agency?

Dr. ANDREWS. The Army has adopted Technology Readiness Levels (TRLs) as the method to measure the maturity of the technologies being developed. The TRLs were identified in the recommendations put forward in the 1999 General Accounting Office Report ("Best Practices: Better Management of Technology Development Can Improve Weapon Systems Outcomes," GAO/NSIAD–99–162, July 1999) citing best practices for the management of technology development. This report indicates that critical technologies and/or subsystems should be at a high level of maturity prior to making the commitment for development and production of a weapons system. The Army has adopted this philosophy and has implemented the use of TRLs as a viable way to track technology maturity level. The Army has taken the lead within the Department of Defense in adopting TRL assessments as a way to monitor technology progress from concept to production. The Army fully supports the use of

TRLs to track technology maturity and will use them as a tool to help assess progress towards achieving the Army Transformation.

Dr. DANIEL. Past use of the Technology Readiness Levels (TRLs) in the Air Force has been sporadic and localized. However, under recently-revised Department of Defense (DOD) regulations, the use of TRLs will be mandatory for all major acquisition programs. The Air Force has been participating with the other Services, Defense Agencies, and the Office of the Secretary of Defense (OSD) staff in an Integrated Process Team to define the guidelines and framework for implementing and applying TRL assessments in a consistent manner across the Department. Interim guidance based on the results of team's efforts has just been provided by OSD.

Dr. ALEXANDER. The greatest benefit of utilizing the technology readiness level (TRL) description of technology or system maturity is in the establishment of a common language across communities. The TRL descriptions bridge the nomenclature between the research community and operational community enabling a clearer understanding of the maturity of the project. They also establish specific demonstrable milestones to gauge progress of the research and development towards an operational system. A consistent use of TRLs can foster a better understanding of the project timelines, promoting a smoother transition of the projects, especially from 6.3 to 6.4 funding and beyond. When broken down by component technology (as opposed to system), the TRL description can also provide insight into the higher risk components and aid in developing risk mitigation investments.

The advantages of clarifying the technical maturity of a research program to the operational community has led the Defense Advanced Research Projects Agency (DARPA) to adopt the TRL description for the DARPA/Army Future Combat Systems. TRLs are valuable in developing a common understanding for joint DARPA-Service programs. For example, DARPA is finding TRLs useful in developing Future Combat Systems demonstration milestones for the Army acquisition community. As we gain increased experience with the TRL descriptions, I would anticipate that additional DARPA research efforts would adopt that nomenclature.

Admiral COHEN. Within the Department of the Navy S&T programs, the Office of Naval Research (ONR) has established exit criteria as a measure of technology readiness to transition to acquisition/developmental programs. Exit criteria are detailed to define the critical characteristics of the needed technology and are agreed to by ONR and the transitioning office. S&T has also incorporated Technology Readiness Levels (TRL's) into this structure to assist in defining the nature of the demonstration to ensure that the technology meets the desired characteristics.

2. Senator ROBERTS. Dr. Andrews, Dr. Daniel, Dr. Alexander, and Admiral Cohen, what would you anticipate being the greatest challenge or unintended consequence of moving to the Technology Readiness Level system?

Dr. ANDREWS. There have been two major issues that the Army has faced in adopting the Technology Readiness Level (TRL) system. The first, and most prevalent, is the belief that TRLs can assess program risk. The TRLs are a method to measure the maturity of the technologies, not a risk assessment tool. The Army is in the process of adopting a method to develop risk mitigation plans that will address the risk associated with technology development.

Another issue has been the lack of clarification regarding the type of money required for pre-System Design and Definition (SDD) activities that are performed in a Science and Technology environment (S&T). The DODR 5000–2R requires a TRL 6 or 7 prior to a Milestone B decision and entrance into SDD. However, many of the demonstration and evaluation activities associated with achieving that level of maturity are beyond the scope of the level of technical maturity of funding in Budget Activity 3 (BA 3).

Dr. DANIEL. The greatest challenge will be to assure that the Technology Readiness (TRL) guidelines are being implemented and assessments are being made as uniformly as possible by the different Services and Defense Agencies. There is an ongoing effort in the Department of Defense to develop appropriate guidance to provide this uniformity. Additional challenges include lack of experience in utilizing TRLs and the manpower and resource implications associated with implementation.

Dr. ALEXANDER. Given the broad nature of the Technology Readiness Levels (TRLs), confusion and unrealistic expectations can result unless there exists a firm understanding of the milestones and assumptions used in the TRL determination. This requires early communication and coordination between the researchers and operational community in defining the specific demonstrations on a project-by-project basis. TRLs can improve the communications process, but they are not a substitute for good communication. When discussing the TRL of a system made up of developmental components, for example, research and development managers and acquisition managers must communicate carefully to ensure that all understand the

TRLs of the system versus that of the components. The Department is working to apply TRLs to primarily software programs as well, and this also requires precise communication between communities.

The biggest risk in applying TRLs is that there is not a one-to-one correspondence between TRLs and RDT&E research categories (6.1 to 6.6). Since appropriations are categorized by Program Element number (matched to research category), there may arise increased tension between researchers and operators to place more of the financial development burden in the other's financial category. For example, there may be a push by the operational community to spend more of the traditional 6.1 to 6.3 budget maturing the technology to a TRL that mitigates the risk beyond the level that the research community feels is warranted.

Admiral COHEN. Three concerns are immediately identified:

a. The S&T Executive is charged with the responsibility of establishing the TRL's for their Service acquisition programs; the S&T community is not resourced to do this task. There is a risk that program funds will have to be diverted to accomplish that task.

b. TRL's will become a measure of "goodness" of S&T programs and as a result, programs will focus on near-term issues with a loss of creativity and development of break-through or disruptive technology.

c. TRL's will be used for basic scientific research, which by definition is not technology. This will dissuade the best researchers from participating in DOD-related basic research and hinder development of the science base required for new technology.

DIRECT HIRE AUTHORITY FOR PERSONNEL

3. Senator ROBERTS. Dr. Andrews, Dr. Daniel, and Admiral Cohen, last year Congress provided laboratory directors the direct hire authority for personnel. This allows the directors to bypass the usual process of hiring which can take anywhere from 3 to 18 months.

Could you comment on the effectiveness of this authority and whether it has been fully implemented in your labs?

Dr. ANDREWS. The "direct hire" authority under Section 245 of the National Defense Authorization Act for Fiscal Year 2000 has not been implemented to date. On June 21, 2000, Mr. Aldridge, Dr. Chu, and Mr. Frame co-signed a memorandum to the services providing implementing instructions for Section 245. As a result of this guidance, within the Army, the Office of the Assistant Secretary for Manpower and Reserve Affairs has the lead for implementing this guidance. The purpose is to remove, to the extent permitted by law, any existing Department of Defense (DOD) and component impediments, including regulations, policies, procedures, and practices to expedited hiring authority by the directors of the selected laboratories and test and evaluation centers. The Army is identifying policies, procedures, practices and regulations that will be waived and reports back to DOD by mid August. Until these impediments have been waived and the selected directors for the pilot program have been able to implement the expedited hiring authority, I cannot comment on its effectiveness.

Dr. DANIEL. This authority has not yet been implemented in the Air Force Research Laboratory. We are currently awaiting authority and implementation guidance from the Office of the Secretary of Defense. Once fully implemented, I expect the authority to have a very positive effect on our ability to attract and quickly hire individuals that are among the Nation's best technical talent.

Admiral COHEN. Section 1114 of the NDAA for fiscal year 2001 (*Clarification of Personnel Management Authority*) appears to offer the Secretary of Defense broad authority to create a new personnel system for the S&T Reinvention Laboratories participating in the fiscal year 1995 personnel demonstrations, including the possibility of direct hire authority without competition. However, whether this potential will be realized will depend largely on the interpretation accorded this provision by the Office of the Secretary of Defense (OSD), where action on implementation is still pending.

DARPA FOCUS AREAS

4. Senator ROBERTS. Dr. Alexander, what process does DARPA undertake to determine which technologies to focus on and who sets the research agenda for the agency?

Dr. ALEXANDER. DARPA's main mission areas—solve national-level problems, enable operational dominance and invest in high-risk, high-payoff technologies—have endured since the agency's founding in 1958. Within each main area, specific investments change over time. Strategic decisions for the first mission area, solving national-level problems, are based on the concerns articulated by the highest level of government and the Department of Defense. Technologies pursued in the second area, enabling operational dominance, may be for needs articulated by the Military Services, Joint Chiefs of Staff or Unified Commanders. The Future Combat Systems program is example of an investment that DARPA is undertaking because the Army leadership expressed a need for which DARPA had ideas for technical solutions. Other investments in the operational dominance area could be based on DARPA ideas for future military capabilities—DARPA technologists and management see a technology that presents an opportunity for improved military capability. An example in this area would be stealth—technologists articulated the possibility of an aircraft that would be difficult to see on radar. Investments in the third main mission area, high-risk, high-payoff technologies, are based on technological opportunities seen by DARPA experts.

This explains how DARPA sets its broad research agenda. Below this, to a very large extent, DARPA is driven by technical opportunities. We hire preeminent technical experts and ask them to bring us unique, innovative ideas that will have a revolutionary impact on national security. The Director and I review those ideas and determine funding levels that will allow the program manager to mature the idea, demonstrate its potential and lower its technical risk. Lowering risk and conducting demonstrations allow the Military science and technology community and industry to decide to incorporate the technical idea into their programs.

This entire process, of course, operates in conjunction with planning processes within the Department of Defense such as the science and technology and budgeting processes. In addition, DARPA management and program managers also benefit from findings from the Defense Science Board, interagency science and technology groups, and technical experts within and outside of the Federal Government, as well as vision statements articulated by the Joint Chiefs, Military Services and Unified Commanders.

CHEMICAL AND BIOLOGICAL AGENT DECONTAMINATION

5. Senator ROBERTS. Admiral Cohen, decontamination of personnel and equipment exposed to a chemical or biological agent is a continuing problem for the Services. Military personnel must be able to survive and fight in any environment regardless of whether an adversary uses a chemical or biological agent against them. One of the functions of the Marine Corps' Chemical and Biological Incident Response Force (CBIRF) is to quickly decontaminate marines and their equipment so that they can continue their operations unhindered. To further meet the decontamination challenge, the Marine Corps has been testing a new technology called electro-chemically activated (ECASOL) decontamination solution. In a recent three-day test conducted by the Marine Corps' Systems Command and a CBIRF team, the ECA technology demonstrated that it was an effective decontaminate and exceeded all test requirements.

What are your thoughts on the problems of chemical and biological agent decontamination and the use of the electro-chemically activated technology?

Admiral COHEN. The Marine Corps began testing ECASOL, the electro-chemically activated technology, in February 1998. Marine Corps' Systems Command utilized Battelle Memorial Institute as the independent "honest broker" tester for this product. A testing regime was developed consisting of five phases. Four of the five chases have been completed. Up to this point, the indications are that ECASOL has performed well in killing efficiency, has demonstrated its viability as a skin decontaminant, and has demonstrated efficacy against a number of chemical and biological agents. However, further testing on ECASOL's effectiveness on a variety of surfaces is still required. Thus, the nature and extent of any problems associated with the use of ECASOL as a decontaminant are still to be determined.

QUESTIONS SUBMITTED BY SENATOR RICK SANTORUM

DOD BASIC RESEARCH FUNDING

6. Senator SANTORUM. Mr. Aldridge and Dr. Etter, with the exception of the fiscal year 2001 funding spike, funding for Department of Defense basic research has been consistently underfunded. Congress shares some of this blame, as it has taken funds from these crucial accounts and used them to pay for the near-term modernization or procurement needs of today's military.

Recently, I met with leaders of the information technology industry and discussed issues of concern as well as industry priorities. These individuals were concerned with the level of basic research funding in the United States. These leaders emphasized that without increased investment in Department of Defense basic research, the number of graduate student opportunities to pursue Department of Defense research cannot increase. A decline in the pool of scientists, engineers, mathematicians, and skilled technicians will prevent the Department of Defense from achieving success in the pursuit of "leap ahead" technologies.

With this in mind, I offered an amendment to the Senate's Fiscal Year 2002 Budget Resolution which calls for increasing the level of Department of Defense basic research conducted in American universities by $353.5 million for fiscal year 2002. In addition, I recently circulated a letter to the Defense Appropriators among my colleagues which seeks a $1.03 billion increase in our S&T program funding levels for fiscal year 2002.

Will both of you please address the importance of DOD basic research to realizing "leap ahead" advances in military capabilities.

Mr. ALDRIDGE (on behalf of himself and Dr. Etter). DOD basic research is a wellspring of new knowledge and understanding that underpins future defense technologies. While basic research sometimes pays immediate dividends, its full impact usually isn't apparent until much later. With the benefit of hindsight, we can discern the patterns of research that spawned today's revolutionary military capabilities, including the Global Positioning System, stealth, night vision, and precision strike. We expect equally important new capabilities to emerge over the long term from today's investments in basic research. Some of the exciting basic research areas in which the DOD currently invests are areas pertinent to technologies such as nanotechnology, smart materials and structures, information technology, human-centered systems, compact power and biomimetics.

7. Senator SANTORUM. Mr. Aldridge and Dr. Etter, please address how funding levels for DOD basic research impact not only military capabilities, but also the pool of skilled scientists and engineers who will drive innovation and change.

Mr. ALDRIDGE (on behalf of himself and Dr. Etter). Each year DOD provides support to about 8,000 graduate students pursuing advanced degrees in science and engineering fields critical to national defense. The DOD basic research program provides the majority of this support, primarily through the employment of graduate students as research assistants on defense research projects. Research assistants receive training in the performance of research, satisfying requirements toward their degrees as an integral part of the work they perform on the projects. The basic research program also supports the National Defense Science and Engineering Graduate Fellowship Program, a way of honoring and encouraging the best and brightest students in defense-critical fields. Through these mechanisms, the DOD helps to ensure the future availability of science and engineering talent for defense needs.

8. Senator SANTOURM. Mr. Aldridge and Dr. Etter, do you believe that the levels of funding for basic research are adequate to propel transformation throughout the services?

Mr. ALDRIDGE (on behalf of himself and Dr. Etter). The level of basic research funding in the DOD Amended Budget for fiscal year 2002 reflects our carefully considered judgment on the best programmatic balance within available resources. There are abundant scientific and technical opportunities to be exploited with additional basic research resources, but there also must be a good balance in the investments among all of the components of Research, Development, Test and Evaluation (RDT&E). A balanced RDT&E investment strategy is important to help assure that basic research results are fully utilized in a timely way, through technology transition to applied research and ultimately to development of defense systems. I therefore urge your full support of the amount requested for basic research.

EASE OF INDUSTRY PARTICIPATION IN MILITARY R&D

9. Senator SANTORUM. Mr. Aldridge, do you believe that there are changes that the Department can take to make it easier for industry to participate in military R&D efforts?

Mr. ALDRIDGE. Yes. There are changes in policy and changes in practice that can make it easier for industry to participate in military R&D efforts.

In the policy arena, I issued on May 16, 2001, a memorandum for the Secretaries of the Military Departments and Directors of Defense Agencies that makes clear that we will not require or encourage contractors to supplement DOD appropriations by bearing a portion of defense contract costs, whether through use of their Independent Research and Development (IR&D) funds or profit dollars. Instead, we will structure contracts to permit contractors to earn a reasonable return in exchange for good performance. In today's environment of reduced defense spending and fewer new program starts, contractors are far less likely than in the past to invest in defense R&D contracts. The risk is simply too great. If a contractor takes the risk, and follow-on work that would provide the return on investment does not materialize, the contractor's financial health may be in jeopardy, along with its ability to attract the resources and talent necessary to continue to undertake challenging technical initiatives.

Another policy step in this direction, implemented in the June 10, 2001, issuance of the acquisition regulation, is the requirement that program managers plan for the use of technologies developed under the Small Business Innovation Research (SBIR) program, and give favorable consideration for funding of successful SBIR technologies. I will be reviewing these plans at milestone and program reviews for ACAT I programs.

In terms of practice, actions speak louder than words. There has been a policy that funding in the Future Years Defense Plan (FYDP) support a program as presented at a major decision review. Over time, that policy has received varying degrees of attention. Consistent with my belief that we should not require contractors to supplement DOD appropriations, I plan to enforce this policy. If a program is going to get a favorable decision, the program funding must be adequate to support implementation of the acquisition strategy. Also in the realm of practice, we will continue to leverage commercial and dual-use technologies to the maximum extent possible, which allows private entities otherwise involved in commercial efforts to apply them to DOD needs. We will continue to find ways to tailor our contracts or other business arrangements so they meet the needs of the nontraditional defense contractors as well as the Department.

In addition to the policy changes, we are in the process of refining the investment in the Science and Technology portion of Research and Development, with increased investment in development of prototype systems, such as seen with the Advanced Concepts Technology Demonstration program. These demonstration programs have a heavier proportional industrial investment, which should also spur industrial Research and Development.

BENEFITS OF MEMS RESEARCH

10. Senator SANTORUM. Dr. Gabriel, how might MEMS research provide benefit to the military as it begins to transform to meet 21st century threats?

Dr. GABRIEL. Experiences in recent conflicts and the evolving role of the U.S. military stressing rapid response to varying missions have demonstrated the compelling advantage of accurate and timely information coupled with smart weapons systems. The resulting combination of awareness and lethality will be key to increasing and projecting military capability in the 21st century.

MEMS embedded into weapons systems, ranging from competent munitions and sensor networks to high-maneuverability aircraft and identify-friend-or-foe systems, will bring to the military new levels of situational awareness, information to the warrior, precision strike capability, and weapons performance/reliability. These heightened capabilities will translate directly into tactical and strategic military advantage, saved lives, and reduced material loss.

MEMS will create new military capabilities, make high-end functionality affordable to low-end military systems, and extend the operational performance and lifetimes of existing weapons platforms. For example, MEMS will enable complete inertial navigation units on a chip, composed of multiple integrated MEMS accelerometers and gyroscopes. The inertial navigation systems of today, however, are large, heavy, expensive, power-consumptive, precision instruments affordable only in high-end weapons systems and platforms. Inertial navigation on a chip would not only make it possible to augment global positioning satellite receivers for battlefield tracking of troops and equipment, but would also provide guidance for high-volume munitions that are currently unguided. MEMS inertial navigation units on a chip will achieve performance comparable to or better than existing inertial navigation systems and be no larger, costlier, or more power consumptive than microelectronic chips.

In addition to single-chip inertial navigation units, there are many opportunities for MEMS insertion into DOD systems across a number of technologies alud products that include:

Distributed unattended sensors for asset tracking, border control, environmental monitoring, security surveillance, and process control;

Integrated fluidic systems for miniature chemical/biological analysis instruments, hydraulic and pneumatic systems, propellant and combustion control, and printing technology;

Low-power, high-resolution, small-area displays for tactical and personal information systems;

Embedded sensors and actuators for condition-based maintenance of machine and vehicles, on-demand amplified structural strength in lower-weight weapons systems/platforms and disaster-resistant building;

Radio frequency elements for agile, secure and low-power communications systems;

Acoustic devices and arrays directional microphones, acoustic signature and security sensors and ultrasound ranging/detection;

Integrated microoptomechanical components for identify-friend-or-foe systems, displays and fiber-optic switches/modulators; and

Active, conformal surfaces for distributed aerodynamic control of aircraft, adaptive optics, and precision parts and material handling.

11. Senator SANTORUM. Dr. Gabriel, does MEMS have utility for the Army's Objective Force—a force that will rely on situational awareness and speed, as opposed to force-on-force lethality?

Dr. GABRIEL. Yes—most definitely and in many ways.

12. Senator SANTORUM. Dr. Gabriel, if so, in what way?

Dr. GABRIEL. As just one example, MEMS creates unprecedented situational awareness capability by enabling the use of as many as 100,000 to 1,000,000 micro-sensors distributed over a theater of operations and concentrated in critical target areas.

These micro-sensors would be able to provide continuous surveillance of concealed and moving targets with an array of different types of detectors including but not limited to: biological. chemical, optical imaging, acoustic, seismic, and electromagnetic. Advanced energy systems coupled with covert communications would transmit data to overhead receiving systems for processing into detection, identification, and target data.

Some of the micro-sensors would have ground or air mobility to allow advantageous placement and observation. It is anticipated that some degree of robot intelligence could also be incorporated to enable the micro-sensors to investigate concealed targets on their own.

This class of surveillance and targeting system, together with the more conventional remote air- and space-based sensors, would allow future U.S. military forces, like the Army's Objective Force, to find, identify, and target aggressor military equipment and forces that are concealed under foliage, in buildings, and in underground facilities. In addition, such a wide-area, dense and penetrating sensor capability would allow identification and targeting of moving targets, even under foliage-a capability that challenges present-day stand-off systems.

13. Senator SANTORUM. Dr. Gabriel, one of the concerns associated with the use of a chemical or biological agent is the invisibility of the threat.

Does MEMS technology have application to chemical or biological threats?

Dr. GABRIEL. Yes, and again in multiple ways. In a recent report of the Defense Science Board, pro-active approach to defend against chemical and biological threats outlined eight major elements:

1. Blanket coverage by affordable networks of detectors and sensors;
2. Biosignature recognition of engineered BW agents;
3. Automatic triggering of neutralization, protection, and containment responses;
4. Pre-positioned infrastructure protective systems;
5. Presymptomatic detection of infected individuals for infection control and early therapy;
6. Novel non-agent-specific immune enhancement pharmaceuticals, available to protect against novel agents and agents engineered for resistance;
7. Revolutionary production capability for rapid supply (less than 7 days) of synthetic designer vaccines/therapeutics; and
8. Source attribution credible to the international community, through pathogen biosignature, intelligence, and forensics.

As in the answer and remarks to questions 11 and 12, MEMS technology enables a variety of chemical and biological sensors at a cost, size and in numbers that allow for large-area continuous monitoring sensor networks of the type outlines in element #1 above.

In contribution to element #2, new classes of chemical and biological "laboratories-on-a-chip" are creating hand-held, field-deployable systems to quickly and accurately detect both natural and engineered chemical and biological agents. Such systems today are large instruments in a fixed, remote laboratory where samples must be sent and may take days to weeks to get identification.

Addressing both elements #7 and #2, emerging MEMS-based fluidic systems offer the potential of implanted drug-delivery systems that detect the onset of symptoms due to a chemical and/or biological attack in an individual and immediately begin delivering antidotes and antibiotics at the right time and in the right quantities to protect the individual and neutralize the threat.

ETHICAL, LEGAL AND SOCIETAL IMPLICATIONS OF NANOTECHNOLOGIES

14. Senator SANTORUM. Dr. Kuper, currently, the NNI is balanced across five broad activities: fundamental research; grand challenges; centers and networks of excellence; research infrastructure; and the ethical, legal, and societal implications.

What do you believe are some of the ethical, legal and societal implications behind nanotechnologies?

Dr. KUPER. Senator Santorum, as usual, you pose an extremely challenging and far-reaching question. Although difficult for one person to answer such a question on behalf of entire community, I will try my best.

To understand the ethical, legal and society implications of nanotechnology one must first understand the workings of the natural world. Nature answers to no human and has no synthetic logic, moral or legal structure. Some would say the sole governor of nature is a higher power. Humankind governs humankind. Society functions by relying on a previously established, although always changing, set of rules, which define the ethical, legal and societal protocols by which we live.

Nanotechnology is the technology of science on the nanoscale, the size scale of atoms and molecules, the building blocks of life and world around us. Nanotechnology is about perfecting engineering at this level. When one perfects molecular engineering, one comes very close to the natural world. This means synthesizing the natural world in an unnatural place, the laboratory. With this, the governor changes from a higher power to mankind. This is the ethical, legal and societal implication of nanotechnology.

From here inwards it is a purely philosophical discussion. Is humankind brought into the world as a tabula rasa, or are we born with an innate sense of good and bad, right or wrong? The answers to questions like these will no doubt determine our level of fear of our neighbors. Our fears will, as they usually do, determine our actions. So, I mean to say that how society handles the fruits of nanotechnology will depend on how we see our intent and this will be the implication.

One should not stop for too long on this, however, to think our future holds only fears and wild heights of unchecked power, all from nanotechnology. Uncovering the beauty of the natural world and understanding its inner workings will equally impact our future in a very positive way. The implication of this will most likely be seen in a richer societal appreciation for the environment and how to protect it, an understanding for how stop disease, an appreciation for life that causes us to rethink producing things that destroy it.

If I could list just a few of what I think are some of the ethical, legal and societal implications behind nanotechnology they would be patent disputes, such as what is happening now over the human genome project, moral issues of who should control the beginning and end of human life, scientific questions relating to anti-biological warfare agents and vaccines, making drug discoveries and advances in materials which could save lives available to public and most interesting will be the amendments to our legal system to better enable society to change with changing technology and standard of living. Our legal system must be vigilant because each plateau that technology reaches presents new legal questions. For example, who would have thought that technology would produce the issueof whether or not an electronic signature is legally valid?

Our quandaries over implications such as these are not new to us. Perhaps this is best evidenced by Albert Einstein in an address to the California Institute of Technology in 1931, where he said, "Concern for man himself and his fate must always form the chief interest of all technical endeavors, concern for the great unsolved problems of the organization of labor and the distribution of goods—in order that the creations of our mind shall be a blessing and not a curse to mankind. Never forget this in the midst of your diagrams and equations."

ARMY SCIENCE BOARD STUDY OF VENTURE CAPITAL

15. Senator SANTORUM. Dr. Andrews, earlier this year, the Army tasked the Army Science Board with exploring venture capital as a means toward maintaining the pace of modernization. Specifically, Paul J. Hooper, then-Assistant Secretary of the Army for Research, Development, and Acquisition, asked the Army Science board to study: (1) methods to obtain complementary funding resources for long-term research and development strategic objectives; (2) options and approaches to provide these resources; establishing an Army venture capital fund to work with venture partners for promising new technologies; developing more robust partnerships and collaborations with industry and academia; and (3) using a small portion of Army funds to sponsor new technologies in start-up companies that offer high potential as well as commercial benefits to the Army. Are you familiar with this tasking?

Dr. ANDREWS. I am.

16. Senator SANTORUM. Dr. Andrews, if so, what are your comments on the merits of this approach?

Dr. ANDREWS. Using the Army Science Board to study this issue makes sense and I wholly support their effort. As to whether the use of venture capital is an appropriate means of maintaining the pace of modernization is another question. The Army Science Board has not yet completed its study. I would prefer to hear the specific responses of the Army Science Board before providing my comments. Whether the venture capital approach for the Army (or any of the services) is viable remains to be seen. The jury is still out on the experiment with the Central Intelligence Agency and In-Q-Tel. However, the Army already has many tools today that it uses to promote innovation. We partner with industry and academia through collaborative technology alliances to conduct fundamental research in where the private sector has the technical lead and incentive to invest. The use of Other Transactions when there are obstacles to attracting non-traditional suppliers was pioneered by the Defense Advanced Research and Projects Agency and is being used by the Army. Our laboratories take advantage of Cooperative Research and Development Agreements to co-invest (labor and facilities) in the development of technology. Another example is our alignment of the Small Business Innovative Research program with Future Combat Systems technologies and with Science and Technology Objectives, Advanced Technology Demonstrations and Advanced Concept Technology Demonstrations to maximize the utility of products from small and disadvantaged businesses.

17. Senator SANTORUM. Dr. Andrews, why is this approach necessary when we already have DARPA, an entity that is the military's high-risk manager for research and development?

Dr. ANDREWS. Clearly the Army does not intend to duplicate the Defense Advanced Research and Projects Agency. However, one could ask whether the venture capital approach fits the "R" or the "D" part of Research and Development. Venture capitalists are interested in bringing mature technology to market quickly and so the fit may be better on the development side.

18. Senator SANTORUM. Dr. Andrews, why would commercial or private sector entities want to invest in the Army when it lacks the resources necessary to sustain many of its high priority programs and initiatives?

Dr. ANDREWS. The Army contracts with industry and academia for services and equipment. There are opportunities of mutual interest where cost sharing is viable. The Army does attract the best and brightest of both industry and academia to be suppliers to the Army needs. If we have barriers to contracting with certain parts of the commercial sector, we need to find ways to overcome them. The use of Other Transactions is one. There may be others. We have tasked the Army Science Board to look into the venture capital area. We await their report.

FUTURE COMBAT SYSTEMS (FCS) PROGRAM

19. Senator SANTORUM. Dr. Andrews, based on your assessment of historical trends for Army Science and Technology investment, are these reasonable dates?

Dr. ANDREWS. The Army plans to initiate Future Combat Systems (FCS) System Design and Demonstration (formally Engineering and Manufacturing Development) in fiscal year 2006, production in fiscal year 2008, and fielding in fiscal year 2010. This schedule implements innovative approaches, such as (1) placing greater reliance on modeling and simulation to reduce cycle time; and (2) testing requirements, and concurrent subsystem development during the demonstration phase. I can say that when initially fielded, FSC will possess many, but not all, of the capabilities desired by the user. In the spirit of the new Department of Defense acquisition policies, we are planning from the outset for upgrades to FCS to enhance its capabilities. It is our intention for FCS to have an open architecture so that new technologies can be inserted seamlessly as they become mature. Yes, those fielding dates are reasonable if we work to streamline acquisition and use spiral development to provide increasing competition for FCS over time.

20. Senator SANTORUM. Dr. Andrews, that is, is the plan adequately resourced or are there funding shortfalls associated with the plan?

Dr. ANDREWS. The Future Combat Systems (FCS) Science and Technology program is adequately funded, based on current estimates. In the near future, the government will receive results from the competitive concept design phase of the program. The Army will carefully review that information to assess its implications on program funding. The Army FCS program is funded at approximately $500 million per year, and we continue to rely on the financial and intellectual help from the Defense Advanced Projects Research Agency. The FCS program was aided greatly by the $46 million that Congress added to our fiscal year 2001 budget last year, and we appreciate that help very much.

21. Senator SANTORUM. Dr. Andrews, do you believe that this strategy fits the profile of a "high risk" acquisition strategy?

Dr. ANDREWS. The Future Combat Systems (FCS) program is, indeed, an aggressive program. We are challenged to concurrently develop the design concepts, enabling technologies and operational concepts. All these efforts will be performed on a compressed schedule so that we can field FCS in this decade. The Army needs to achieve the Objective Force as quickly as possible in order to remain relevant and postured to meet the Nation's needs. To paraphrase General Shinseki, the Army's Chief of Staff, we recognize that this is a tough challenge, but if we do not try, we surely will not field FCS as soon as possible.

22. Senator SANTORUM. Dr. Andrews, how might the risk associated with this schedule be reduced?

Dr. ANDREWS. The Army has taken steps to reduce risk by seeking competitive solutions, by increasing funding for the collaborative program and the enabling technologies, and by introducing management tools. For example, to ensure we understand the maturity of the technologies being developed, the Army has adopted Technology Readiness Levels (TRLs). The Army has taken the lead within the Department of Defense in adopting TRL assessments as a way to monitor technology progress from concept to production. By understanding the maturity of critical technologies, we can develop the plans to manage the risk.

TRANSFORMATION COSTS

23. Senator SANTORUM. Dr. Andrews, General Accounting Office (GAO) estimates that Transformation may cost upwards of $70 billion over the next 12–15 years. Do you believe that the Army will receive the level of financial support from the Office of the Secretary of Defense (OSD) to aggressively support this process?

Dr. ANDREWS. I can only speak for the Science and Technology (S&T) investments in the Army's budget. These investments are focused on achieving the Objective Force for the Army's Transformation vision. The Army's Fiscal Year 2002 Budget request for S&T is $1.58 billion. This is a 22.5 percent increase over the fiscal year 2001 request of $1.29 billion, and clear evidence of the Army's commitment to achieve Objective Force capabilities, such as the Future Combat Systems, by the end of this decade. The Army has reprogrammed funds from within its own total obligation authority to increase its S&T accounts. The Office of the Secretary of Defense has also supported the Army's desire to achieve Objective Force capabilities by providing additional funds for S&T in fiscal year 2002.

QUESTIONS SUBMITTED BY SENATOR MARY L. LANDRIEU

TECHNOLOGY TRANSITION ISSUES

24. Senator LANDRIEU. Mr. Aldridge and Dr. Etter, the Comptroller General has found that private industry fields new products faster and more successfully because they make sure that new technologies have been proven in the laboratory before they fly to incorporate them into new products. According to GAO, "It is a rare pro-

gram that can proceed with a gap between product requirements and the maturity of key technologies and still be delivered on time and within costs."

Do you agree that problems with immature technologies can slow down an entire acquisition program and unnecessarily lengthen the entire acquisition cycle?

Mr. ALDRIDGE (on behalf of himself and Dr. Etter). Yes. I think this is made even more complex by the nature of our business—that is, dealing with the development of high-risk, high-payoff, revolutionary new warfighting technologies that provide our forces the technological leap-ahead advantage on the battlefield (e.g., low observables, precision strike, and unmanned systems). These technologies may take many years to develop and mature in the laboratory environment. The challenge is to reduce the technological risk to the point that enhancements or leap-ahead capabilities can be efficiently integrated into program planning.

25. Senator LANDRIEU. Mr. Aldridge and Dr. Etter, do you see spiral development, with the sequential incorporation of new technologies as they mature, as an appropriate response to this problem?

Mr. ALDRIDGE (on behalf of himself and Dr. Etter). Yes. The new DOD 5000-series documents specifically address this issue and provide opportunities to insert mature technology at various phases in the acquisition process and supports the evolutionary development of systems. The new process requires more involvement and collaboration between the S&T and acquisition communities, requiring an agreement on the technology maturity level before insertion in the weapon system.

26. Senator LANDRIEU. Mr. Aldridge and Dr. Etter, earlier this year, DOD Directive 5000.2 was revised to require that key technologies reach a specified level of technological maturity before they may be incorporated into acquisition programs.

Are you familiar with this change, and do you support it?

Mr. ALDRIDGE (on behalf of himself and Dr. Etter). Yes. I think the use of Technology Readiness Levels (TRLs), or an equivalent assessment method, is a positive step in reducing the acquisition cycle time. The assessments will be implemented for all Major Defense Acquisition Programs and Major Automated Information System Acquisition Programs. We have published interim guidelines on use of TRLs that establish a technology readiness assessment process, definitions for TRLs, and elements for a technology readiness agreement between the acquisition program manager and technology provider. This will be incorporated into the next update to the DOD 5000.2 Regulation and will be monitored over the next 18 months to evaluate the impact and adjust the process, as necessary.

Last year, a task force of the Defense Science Board on the health of the defense industry recommended that the Department revise the front end of the acquisition process to, among other things: (a) explore more technology options prior to program commitment; and (b) require that Research and Development programs be more separate from production programs. These recommendations appear to be consistent with GAO's findings that we need to mature our technologies more, and find out which ones really work, before we incorporate them into production programs.

27. Senator LANDRIEU. Mr. Aldridge and Dr. Etter, are you familiar with these recommendations, and do you support them?

Mr. ALDRIDGE (on behalf of himself and Dr. Etter). Yes. I think the evolutionary acquisition process will steer the exploration of more technology options. The dialogue that occurs between S&T and acquisition managers as they establish their Integrated Product Teams (with industry and academia) will drive this. This will result in more ideas coming to the table than might otherwise occur if the technologists work on an issue in the laboratory. Second, the need to have both the acquisition and S&T players agree to a TRL level will ensure the best technology options are pursued before inclusion on acquisition programs.

DIRECT HIRING AUTHORITY FOR LABORATORY DIRECTORS

28. Senator LANDRIEU. Mr. Aldridge and Dr. Etter, over the last 2 years, Congress has enacted a series of legislative provisions designed to provide additional flexibility in the personnel system of the defense laboratories, to make it easier for the laboratory directors to recruit highly-qualified scientific and technical staff. However, the Department appears to have been unwilling to use some of this authority. In particular, the Department has not given the laboratory directors "direct hiring authority", as authorized by the last two Defense Authorization Acts.

Do you agree that laboratory directors would be better able to compete for highly skilled scientific and technical staff if we give them direct hiring authority?

Mr. ALDRIDGE (on behalf of himself and Dr. Etter). I do believe that "direct" hiring authority will allow the laboratory directors to better compete for highly skilled scientific and technical staff. We are using the term "expedited hiring authority" to frame the efforts that DOD has in progress in this area.

29. Senator LANDRIEU. Mr. Aldridge and Dr. Etter, if so, will you take advantage of the legislative authority we have given you to address this issue?

Mr. ALDRIDGE (on behalf of himself and Dr. Etter). I have been working very closely with the Under Secretary of Defense for Personnel and Readiness in identifying and initiating various activities that will take advantage of legislative authorities for hiring highly skilled scientific and technical staff. On June 21, 2001, the Services were authorized waiver authority for actions pursuant to section 245 of the National Defense Authorization Act (NDAA) Fiscal Year 2000 and section 246 of NDAA Fiscal Year 1999. These actions should expedite hiring of scientist and engineers. In addition, we asked the services to identify and to waive policies, procedures, practices, and regulations not specifically required by law that restrict or otherwise impede the ability of the laboratories to exercise expedited hiring authority for personnel within their organizations.

30. Senator LANDRIEU. Mr. Aldridge and Dr. Etter, on July 17, the authorities provided by section 1113 of the NDAA Fiscal Year 2001 were delegated to the appropriate DOD components.

Are there other authorities that you think you may need to revitalize the laboratories and ensure that they continue to contribute to defense S&T?

Mr. ALDRIDGE (on behalf of himself and Dr. Etter). We are currently working with General Counsel and Office of Management and Budget to define additional authorities that would benefit the Laboratory Directors. This is an on-going process and we are committed to working with Congress for the purpose of defense laboratory revitalization. It's in the best interest of national defense to do so.

DUAL USE TECHNOLOGIES

31. Senator LANDRIEU. Mr. Aldridge and Dr. Etter, over the last several years, the Department of Defense has attempted to make increasing use of technologies developed in the private sector. These technologies frequently need to be adapted for defense use—either at the front end, as they are being developed, or at the back end, after they have been developed. The Dual Use Applications Program (DUAP) and the Commercial Operation and Support Savings Initiative (COSSI) have been funding mechanisms through which DOD has supported such adaptations.

Are you familiar with the DUAP and COSSI programs, and do you know if the Department plans to continue funding these programs?

Mr. ALDRIDGE (on behalf of himself and Dr. Etter). Both these programs leverage commercial technology for defense purposes. The Dual Use Science and Technology (DUST) Program (formerly DUAP) forms partnerships with industry to develop technologies having commercial and military applications. For example, the DUST program developed an affordable Antilock Brake System for both commercial trucks and the Army's High Mobility Multi-purpose Wheeled Vehicles (HMMWVs) to improve safety and performance.

COSSI is an innovative program that adapts commercial technologies for use in military systems to increase reliability and reduce operations and support costs. Since 1997 we've initiated 77 COSSI projects.

The President's Budget request for fiscal year 2002 includes $10.8 million for COSSI and $30 million for the Dual Use Science and Technology program.

32. Senator LANDRIEU. Mr. Aldridge and Dr. Etter, would you agree that, regardless whether the Department continues to fund the DUAP and COSSI programs, it is going to have to find a way to fund the adaption of commercial technologies to defense uses?

Mr. ALDRIDGE (on behalf of himself and Dr. Etter). Yes. In some areas key to defense, commercial firms are the technology leaders. We will need to take advantage of these technologies if we are to continue to deploy the most advanced weapon systems in the world. For example, one COSSI project leveraged commercial satellite tracking technology to maintain continuous control of in-theater vehicles. After successful demonstration of the prototype developed under the COSSI program, the company received an indefinite delivery, indefinite quantity contract for terminals and support services.

FUNDING FOR MAJOR RANGE AND TEST FACILITY BASES

33. Senator LANDRIEU. Mr. Aldridge and Dr. Etter, over the last decade, we have cut the operating and investment budget for our Major Range and Test Facility Bases by more than a billion dollars. The remaining dollars are stretched far too thin to cover needed upgrades to even the most valuable of our test facilities.

What can we do to reverse this process and make the investments we need in our test ranges? For example, is there a way that we could increase the level of customer funding to cover capital improvements, or attract private investment to make needed upgrades to our most critical test facilities?

Mr. ALDRIDGE (on behalf of himself and Dr. Etter). The Department has reduced the operating and investment funding for the Major Range and Test Facility Base to a level that is about a billion dollars per year below the 1990 level. We intend to review this situation during our on-going defense reviews to determine whether we have reduced too far and, if so, make any necessary adjustments to insure that we have adequate test and evaluation capability and capacity.

From a cost accounting perspective, we could certainly develop a methodology for charging the costs of capital improvements to the test customers, but we do not believe that this will enhance testing overall. One of the principal objectives of the current funding policy, when it was created in the mid–1970s, was to insure that funding issues do not inhibit valid testing. This objective is implemented via a policy that specifies that test customers pay for the direct cost of testing, while the test organization used appropriated (institutional) funds to pay for all other operating and investment costs. This was expected to insure that test capabilities would keep pace with weapon developments, and that the operating capacity to perform required testing would exist. During the last decade, this policy has suffered from a shortage of adequate institutional funding. In fact, a recent Defense Science Board Study, completed in December 2000, found that the test centers, due to shortages of funds, have been shifting more cost to the customer. The Defense Science Board believes that we have already shifted too much cost to the weapons programs. It is the position of the Defense Science Board that this shift in cost has been caused by too little operating funds being provided to the test centers and that the increased charges to weapons programs has led to cases of inadequate test and evaluation for programs strapped for funds.

We are attempting to attract private investment. For example, we have entered into a partnership with the Boeing Company and the Air Force, whereby Boeing has provided new capability at one of our test facilities and eliminated some of its own capability. We will continue to pursue partnerships even though there are impediments to this process, such as the tax consequences to private companies for such exchanges. We will continue to explore these cooperative agreements, and other alternatives for maintaining adequate test and evaluation capability. Where necessary, and after thorough evaluation, we will propose enabling legislation to facilitate such agreements.

LABORATORY PERFORMANCE

34. Senator LANDRIEU. Dr. Andrews, Dr. Daniel, and Admiral Cohen, over the last 3 years, a number of outside panels have been highly critical of the performance of the service laboratories. These panels have indicated that the civil service system is slowly calcifying the defense laboratories and depriving them of the new talent that they need to continue to make a valuable contribution to defense Science and Technology (S&T). We have enacted a number of legislative provisions to try to address these problems.

Do you believe that these legislative provisions are having the desired effect, or do we need to consider more drastic measure, like the partial privatization of one of more laboratories?

Dr. ANDREWS. I am fully aware of the Defense Science Board's reports which have indicated that "the capabilities of the laboratories have been seriously diminished over the past decades . . . The major reason for this decline . . . was found to be the severe difficulty that they have in recruiting and retaining high quality professional staff. . ." They go further, stating "that the inadequate salary structure and excessive personnel regulations of the Civil Service System are primarily responsible for this problem." Four of our seven major S&T laboratories have participated in personnel demonstration projects under Public Law 103–337 since 1997. An additional two labs will join the demonstration project by 2002. By 2004 we expect more than 90 percent of our Science and Technology workforce to be under a personnel demonstration project. This law was enacted to specifically tackle the issue of the Civil Service Regulations. For those labs under a personnel demonstration project, we are seeing encouraging results in the areas of recruiting for quality and diversity, retaining high performers, enhancing careers, and partnering with the unions. Our laboratories have begun to aggressively recruit and hire new scientists and engineers, after a decade of major laboratory downsizing, which continues. Competitive pay, particularly in technical areas such as information technology and computer science remains an issue. The recent legislation initiatives, such as the Sections 245 and 246, which are in the process of being implemented, need to be given the opportunity to prove their utility during implementation at the selected sites. At this time, therefore, I do not recommend more drastic measures, like the partial privatization of laboratories.

Dr. DANIEL. Enacted legislative provisions have had a positive impact on our laboratory workforce. For example, the Laboratory Personnel Management Demonstration Project has provided the Air Force Research Laboratory with some of the needed flexibility to enable a more responsive workforce. This Lab Demo initiative has also enabled the Air Force to reward its laboratory workforce for their outstanding contributions to defense science and technology. However, Section 246 of the National Defense Authorization Act for Fiscal Year 1999 and Section 245 of the National Defense Authorization Act for Fiscal Year 2000 have not been fully implemented at this time. I am hopeful that upon full implementation, these initiatives will have the positive effects that are envisioned. Finally, the Air Force is already making considerable and valuable use of the private and academic sectors in the Air Force Research Laboratory. At this time, almost 40 percent of our in-house scientists and engineers are from industry or the university community.

Admiral COHEN. Some legislative provisions have helped the Service laboratories, especially Section 342 of the NDAA for fiscal year 1995 and Section 1107 of the NDAA for fiscal year 2000. Section 342 allows "S&T Reinvention Laboratories" to implement more flexible personnel systems. However, Section 342 demonstrations are limited in terms of coverage, duration, and scope, e.g. they had to be modeled after the so-called "China Lake" personnel demonstration authorized by Title 6 of the Civil Service Reform Act of 1978. This greatly limited the degree to which participating laboratories could experiment with innovative ways to hire, retain, and shape their workforces in response to rapidly changing business conditions. Section 1107 eliminated controls on high-grade scientific and engineering positions, a move that supports retention of high-quality personnel.

However, the Office of the Secretary of Defense (OSD) has only recently moved to begin implementing other legislative provisions, such as Section 245 of the NDAA for fiscal year 2000, and Sections 1113 and 1114 of the NDAA for fiscal year 2001. Letters signed out of OSD on 21 June 2001 and 17 July 2001 directed Service implementation of Sections 245 and 1113 respectively. Implementation of Section 1114 is still pending in OSD. Therefore, the extent to which these provisions will be helpful cannot be fully determined at this point in time. It appears Section 245 will not allow for direct hire without competition the way the private sector does because of remaining barriers posed by Title 5 merit principles. Moreover, Section 245 is a pilot effort limited in terms of coverage (only two labs per Service), duration (3 years), and scope. Of all these legislative provisions, Section 1114 appears to offer the greatest possibility of relief, although its coverage is limited to S&T Reinvention Laboratories participating in the fiscal year 1995 Section 342 personnel demonstrations. Whether this potential will be realized will depend largely on the Office of the Secretary of Defense's interpretation and emphasis of this provision.

In light of the systemic problems facing the Service laboratories, and the urgency to address hem, it appears that incremental approaches and piecemeal legislative efforts may not be enough. Indeed, we are approaching the point of diminishing returns on trying to make Title 5 practices responsive to the needs of a serious research laboratory. The real problem the Service laboratories face is one of governance. The governance under which these laboratories and their Federal employees operate was not designed for operation in a research environment. As a result, great effort is required to make the governance and the research environment coexist. Perhaps a more sensible approach would be to tailor the governance to the research mission rather than the reverse. The DOD research laboratories play an important role in keeping the DOD itself scientifically and technically competent. This would seem to be a good thing, especially in this technically complex and fast-moving world in which the defense of the Nation must now be conducted. It is now time to consider establishing a new goverlance model (personnel, administrative, procurement, facilities) within the Federal Government specifically tailored to the needs of a military research laboratory. This would, if properly executed, eliminate all of the piecemeal fixes which have been tried over the years while still retaining Federal status and competence in an area, i.e., science and technology as it relates to National Defense. In this regard, establishing one or more of the military research laboratories as special Government corporations may have some merit. The customers for the corporations would be the Government itself. The corporations would survive only to the extent that Government funding agencies were prepared to purchase the products/services of the corporations.

Such a plan would appear to have several advantages over the partial or total privatization of a lab: (1) It almost certainly would be less expensive in the long run; (2) The staff of such an organization would remain Federal employees, and thus able to make decisions or render advice without conflicts of interest; (3) It would be more executable; and (4) It should be less controversial.

LABORATORY LEGISLATION

35. Senator LANDRIEU. Dr. Andrews, Dr. Daniel, and Admiral Cohen, are there other steps that you would recommend to increase the flexibility and performance of the defense laboratories.

Dr. ANDREWS. We clearly want to see the effect of Section 245 and 246 on the hiring processes. If those initiatives are not sufficient in making our hiring processes competitive with industry, particularly in the time to make final offers and the time to bring the offeree on-board, then we will need to make further recommendations. I still believe that our salaries are not competitive in areas such as information technology and computer science. The Veterans Administration and other sectors of the Federal medical community can hire at the market rates in certain specialty categories. We need similar authorities to hire in selected areas to insure that we can attract at least the top 10 percent of bachelor graduates in those areas as well as the Ph.D.'s. I believe our work is interesting and attractive. We need the ability to offer the salaries to attract quality scientists and engineers, and keep them.

Dr. DANIEL. Over the past several years, the Air Force has been addressing workforce performance via the Laboratory Personnel Management Demonstration Project. With Lab Demo, the Air Force Research Laboratory has gained some of the needed flexibility to enable a more responsive workforce capable of meeting future defense challenges. Lab Demo's flexibility has resulted in the current laboratory workforce making significant contributions to defense science and technology and being rewarded for it.

The additional flexibility provided by Section 246 of the National Defense Authorization Act for Fiscal Year 1999 and Section 245 of the National Defense Authorization Act for Fiscal Year 2000 will be especially beneficial in the area of new hires. However, since these legislative provisions have not been fully implemented, the Air Force does not recommend additional legislation at this time. I would like to fully implement Sections 246 and 245, evaluate the results, and then make recommendations on other improvements, if needed.

Admiral COHEN. The Service laboratories are one part of a larger defense science and technology structure that includes academic and industrial partners. Each of these organizations plays an indispensable role in the development, production, and deployment of advanced technologies into warfighting systems. For this structure to work properly, all three types of organizations must be staffed by world-class, motivated scientists and engineers. Increasingly, the laboratories must team with these other partners to facilitate technology transfer. There are several legislative barriers that hinder such partnering. Their removal would increase the flexibility and performance of these laboratories.

There have been over 100 studies of some aspect of the Defense RDT&E establishment in the past 40 years, and the recommendations resulting from these studies are remarkably similar. The most significant difference is that the more recent studies often recommend more radical solutions to the problems that continue to confront the DOD labs. Despite the blue-ribbon nature of many of these study groups, only a few, essentially incremental, reforms have actually been implemented. While these reforms have helped, they have not been enough to turn the tide of mediocrity that has been slowly rising over the past decades.

For this situation to be reversed, the country must commit to implementing the most significant lab-related recommendations made by these studies. This will require a willingness on the part of the DOD, the Services, and such other Government entities as Congress, OPM and OMB to admit that if the DOD labs are to be *good,* they cannot be required to operate within the stifling, one-size-fits-all labyrinth of personnel regulations that have been developed over the past 100+ years. A whole new approach in the area of personnel management at the labs is urgently required. There is no lack of good ideas here—what we lack is the will to proceed.

They also must be permitted to operate like the best academic and industrial research labs in such areas as renewal of infrastructure, procurement of capital scientific equipment, and obtaining support services. For example, the current military construction process of competing priorities does not favor the renewal of the laboratory physical plants. This problem could be addressed by legislation that would allow the laboratories to execute a capital purchase program by using funds generated through overhead charged to their customers and from the proceeds of technology transfer activities. Such legislation might also streamline the procurement of capital equipment, a process that is burdened with onerous and unnecessary regulations and timelines that often make it difficult to obtain the latest scientific hardware.

In addition, the labs need to be able to maintain a high percentage of interesting and challenging "hands-on" work. They cannot do this if they are largely relegated to the role of contract monitors. This has been one of the few advantages enjoyed by the DOD labs in the past, but is now threatened by continued pressures to maintain the dwindling defense industrial base in many areas.

Certainly legislation that specifically addressed the needs of the labs in such areas as personnel recruiting, retention and reward; infrastructure renewal; administration and support services; and other areas would go a long way to solving the problems confronting the labs. However, bolder action should be seriously considered for the Navy's Corporate Laboratory, the Naval Research Laboratory, and possibly other Service labs as well. The basic concept of this proposal is described in the answer to question 34 above. Serious consideration should be given to such a concept—failure to take some type of bold action at this time would appear to consign one of the last great Government laboratories to mediocrity.

ARMY SCIENCE AND TECHNOLOGY (S&T) PROGRAM

36. Senator LANDRIEU. Dr. Andrews, the Army has made a commitment to transform itself into a more responsive, more deployable, more capable force over the next decade. Secretary Caldera and General Shinseki have acknowledged that the Science and Technology (S&T) program is crucial to the success of this plan. Is your S&T Program fully-funded through the Future Years Defense Plan (FYDP) to address the requirements of the Army's transformation?

Dr. ANDREWS. As you are aware the Secretary of Defense is directing a Department-wide review of Defense Strategy and is conducting the Quadrennial Defense Review to help shape the FYDP. Therefore, the Department of Defense has not yet determined allocations of the FDYP to specific accounts. Additional funding would be used to reduce risk in S&T programs by increasing options and accelerating technology development.

37. Senator LANDRIEU. Dr. Andrews, where are the shortfalls, and how do you plan to make them up?

Dr. ANDREWS. As you are aware the Department of Defense is conducting a review of Defense Strategy and the Quadrennial Defense Review itself will also help to shape the Future Years Defense Plan (FYDP). Therefore, it is pre-mature for me to comment about shortfalls in Science and Technology until we, in the Army, are provided with information about our resource allocations in the FYDP. Additional funding does help to reduce risk in S&T programs by increasing options and accelerating technology development.

BOTTOM-UP REVIEW OF AIR FORCE SCIENCE AND TECHNOLOGY PROGRAM

38. Senator LANDRIEU. Dr. Daniel, over the last 2 years, this committee has been extremely critical of the Air Force for underfunding its science and technology programs. Last year, we required the Air Fore to conduct a comprehensive, bottoms-up review process to determine what technological challenges it needs to meet to address the needs of the Air Force of the future, and to make sure that its science and technology program is appropriately designed to address those challenges. When do you expect that review to be complete

Dr. DANIEL. The review is on schedule to be completed by October 30, 2001, as required by law.

39. Senator LANDRIEU. Dr. Daniel, will it serve as the basis for future science and technology budget requests?

Dr. DANIEL. The Air Force Science and Technology (S&T) Planning Review, now ongoing in response to the Fiscal Year 2001 National Defense Authorization Act, is identifying the Short-Term Objectives and Long-Term Challenges for the AF S&T Program. It is further assessing what current programs we have in place that address these objectives and challenges, as well as laying out desired programs to fully meet these objectives and challenges. As such, the results of this review will be a major input to the formulation of future S&T budget requests. However, while the review will be an important consideration, we will also factor in the Joint and Air Force strategy documents, Defense planning documents, Defense S&T Plans, and the Air Force Corporate Investment Strategy as we always have.

40. Senator LANDRIEU. Dr. Daniel, do you expect to see a significant increase in the Air Force's S&T budget request this fiscal year?

Dr. DANIEL. Yes. Air Force Science and Technology (S&T) funding has shown a marked improvements for the second year in a row. The Fiscal Year 2002 President's Budget (PB) is up over $150 million for core S&T efforts from the Fiscal Year 2001 PB. This increase includes a sizable gain of almost $120 million in the 6.1, Basic Research, and 6.2, Applied Research, technology base. The 6.3, Advanced Technology Development budget activity on the whole is slightly lower due to the transfer of Spaced-Base Laser program from the Air Force to the Ballistic Missile Defense Organization. We are continuing to work S&T funding levels for fiscal year 2003 and out, and anticipate continuing progress in our future S&T budget submittals.

DARPA FORMAL TECHNOLOGY TRANSITION AGREEMENTS

41. Senator LANDRIEU. Dr. Alexander, in recent years, DARPA has worked closely with the services to identify areas of opportunity and technological needs where DARPA can play an effective role. In some cases, however, we still hear complaints that DARPA initiatives are not ready to transition into production. You told our staff earlier this year that DARPA's job is to prove a concept, for example, by proving out the high risk aspects and showing that the concept is valuable. You stated that it is not necessarily DARPA's job to produce completed designs, because such designs inevitably involve trade-offs and interface decisions that the services must make for themselves.

Do you think that formal technology transition agreements between DARPA and the military services are helpful, or are they likely to be counterproductive?

Dr. ALEXANDER. Formal technology transition agreements can be helpful, but it depends on the circumstances. They are most appropriate when a Service first agrees that they want to take over a DARPA project and the formal agreement is a way to work out and clearly communicate the expectations and commitments of both parties. This is most likely the case with 6.3 system projects that produce something like military specific end items that require more engineering before they can be produced and deployed. Future Combat Systems is a case in point. On the other hand, formal technology transition plans are not useful or appropriate for our 6.1 work and the great majority of our 6.2 work; it's just too early. In those cases, formal agreements are unlikely to be meaningful, and might stifle the innovation and exploration that must occur. The key point about formal agreements is that they are a tool for communicating and focusing, not an end in and of themselves. It's the communication that's crucial to transition.

It would be counterproductive to generally require formal technology transition agreements between DARPA and the Services, even if only for 6.3 programs. For starters, such a requirement could easily degenerate into a paperwork exercise. Far more importantly, it would become one way to stop DARPA programs that challenge the Services' existing technology, systems, or doctrine, and those are exactly the projects DARPA should undertake. DARPA exists in large part to produce radical technical change that challenges the Services before our adversaries do. Hence, DARPA will continue to develop technologies without having a formal technology transition path.

TECHNOLOGY TRANSITION FUNDING

42. Senator LANDRIEU. Dr. Alexander, do you think it would be helpful to have a source of funding within the services to take technologies that have been proven by DARPA and mature them to the point where they are ready to incorporate into weapon systems?

Dr. ALEXANDER. Yes, but I would add not only for DARPA technologies, but for technologies from any source. I fully recognize that the Services must balance many more competing priorities than DARPA does, but I do think such a fund would make it easier and quicker to transition technologies to the Services to be further engineered to meet their requirements. The basic challenge here is that once a technology has proven its worth, and a Service wants to mature it, all the money in an ongoing fiscal year is claimed by specific projects and it takes 2 years to get new money for the technology. A transition fund—a pool that is not preallocated to existing projects but that can be used to seize technological opportunities—seems a logical solution. However, many veterans of the budget process believe that such a fund is unlikely to survive the budgeting and appropriations process, and, even if it does, that it will end up heavily freighted with internal and external approvals that would greatly slow its use. In a time when the DOD is under tight fiscal constraint, this skepticism carries considerable weight. In any event, one key to making such funds useful would be to ensure that the Services could allocate them quickly and with flexibility.

NAVY SCIENCE AND TECHNOLOGY FUNDING

43. Senator LANDRIEU. Admiral Cohen, over the last 2 years, the Navy has undertaken a lengthy planning process to identify "grand challenges" and "future naval capabilities" to serve as a focus for prioritizing future S&T program needs?

Do you expect this planning process to result in a significant realignment of Navy S&T spending in this year's budget?

Admiral COHEN. The Future Naval Capabilities is a process that partners science and technology with both the Navy and Marine Corps military requirement offices and the acquisition offices. The Office of Naval Research (ONR) will invest approximately $500 million in applied research and advanced technology development funding into technologies to achieve the highest capabilities identified by the requirements offices. To focus resources to ensure that these technologies can be delivered in the timeframe need for the transition office, significant realignment of the fiscal year 2002 applied research and advanced technology development programs has occurred. We do not anticipate that there will be a significant realignment on the fiscal year 2002 basic research program.

44. Senator LANDRIEU. Admiral Cohen, will you provide us with visibility not only as to what you have funded and what you have cut, but also into places where you are unable to fund programs that you have identified as important to the achievement of your new S&T goals?

Admiral COHEN. The Office of Naval Research (ONR) will invest over $500 million in applied research and advanced technology development funding into technologies to achieve Future Naval Capabilities. The 12 Future Naval Capabilities that will be funded include:

- Autonomous Operations
- Capable Manpower
- Electric Ships and Combat Vehicles
- Knowledge Superiority and Assurance
- Littoral Anti-Submarine Warfare
- Littoral Combat and Power Projection
- Missile Defense
- Organic Mine Counter Measures
- Platform Protection
- Time Critical Strike
- Total Ownership Cost
- Warfighter Protection

Areas that will receive less funding are environmental quality, advanced logistics technology, portions of the medical research, and portions of advanced electronic warfare research.

Propulsion technology for ships and combat vehicles and combat technology for littoral operations were two areas of research not funded in the original recommendations for Future Naval Capabilities (FNC). These area represent core missions for the Navy and Marine Corps. Therefore, the Navy realigned the FNCs to create the Electric Ships and Combat Vehicles ENC. The Navy added littoral combat technology to the expeditionary logistics FNC to create the Littoral Combat and Power Projection FNC.

QUESTIONS SUBMITTED BY SENATOR MARK DAYTON

RADIATION HARDENED ELECTRONICS INDUSTRIAL BASE

45. Senator DAYTON. Mr. Aldridge and Dr. Etter, I recognize the importance of Radiation Hardened Electronics Technology to the DOD. I also recognize the nature of the technology makes it unique to the DOD and generally not applicable to the commercial marketplace. Because of this, I am concerned with the stability of the industrial base supplying this technology, especially now that there are only two remaining U.S. suppliers of Digital Radiation Hardened Electronics. I also understand that both suppliers are finding it difficult to keep this as a viable business. I was pleased to see the previous DOD direction to the services to make funding available for support of this critical strategic technology and industrial capability.

Is there, in your view, sufficient funding requested in fiscal year 2002 in both S&T and capitalization to maintain this critical Radiation Hardened Electronics Industrial Base?

Mr. ALDRIDGE (on behalf of himself and Dr. Etter). Yes, the funding requested in fiscal year 2002 initiates a 4-year program to purchase capital equipment and perform the research and development necessary to establish the radiation hardened process essential to meet the Department's radiation hardened electronics needs and assure survival of this essential industrial base. The Department's Radiation Hardened Electronics Oversight Council (RHOC) has studied this area in detail and the "leap ahead" technology funding, when supplemented by those in the Council technology development roadmap, will meet our needs.

46. Senator DAYTON. Mr. Aldridge and Dr. Etter, what measure of support do you need from this committee to assure that this critical national capability remains available to support our Nation's defense requirements?

Mr. ALDRIDGE (on behalf of himself and Dr. Etter). The DOD funding request is the level of support we need to meet the radiation survivability needs of our electronic systems and the need for industrial base modernization. Your continued interest will be vital to the success of this effort.

47. Senator DAYTON. Mr. Aldridge and Dr. Etter, what is the status of the report requested by our committees last year?

Mr. ALDRIDGE (on behalf of himself and Dr. Etter). The report requested was delayed because some of the data needed were not available until the Department completed its review of the total fiscal year 2002 budget request. The report is being finalized and will be submitted as soon as coordination is complete.

48. Senator DAYTON. Mr. Aldridge and Dr. Etter, could you please explain what is the DOD's intent with respect to sustaining the radiation hardened electronics industrial base?

Mr. ALDRIDGE (on behalf of himself and Dr. Etter). The performance of many DOD weapons systems requires these highly specialized, radiation hardened electronics components that are only available through the rad hard electronics industrial base. This need will grow as the Department continues to make space operations a priority. Consequently, we are putting special emphasis on ensuring these components are available to DOD systems in the future by establishing the focused DOD radiation hardened electronics "leap ahead" program starting in fiscal year 2002. Additionally, we will continue to "corporately" manage this area through the Department's Radiation Hardened Electronics Oversight Council (RHOC) that reports to me. The RHOC charter requires it to recommend and coordinate actions where a needed industrial capability is at risk.

49. Senator DAYTON. Mr. Aldridge and Dr. Etter, are you intent on supporting multiple vendors?

Mr. ALDRIDGE (on behalf of himself and Dr. Etter). Yes. Our systems are demanding near state-of-the-art electronic performance. We achieve this by leveraging commercial advances in electronics and performing research and development to determine the material, process, layout, and design changes essential to instill radiation hardness. We perform this R&D in a very tight scheduling window with the Department's systems relying on deliveries of advanced radiation hardened electronics to meet performance, weight, and power requirements. There is a history that tells us that when you rely on scientific breakthroughs in a time constrained environment it makes sense to have multiple efforts. Additionally, there are real economic, innovation, infrastructure protection, and assured sourcing benefits to having the competition of multiple vendors.

50. Senator DAYTON. Mr. Aldridge and Dr. Etter, I am aware that there are at least three funding elements essential for preservation of the industrial base including: (1) Science and Technology (S&T); (2) Productization and Qualification (P&Q); and (3) capital equipment.

Has the DOD sufficiently budgeted fiscal year 2002 funding for the P&Q and capital equipment elements in your view and for the number of vendors you intend to sustain?

Mr. ALDRIDGE (on behalf of himself and Dr. Etter). The capital equipment funding is sufficiently budgeted for fiscal year 2002; out-year funding for capital equipment will be addressed in the fiscal year 2003 budget build process. The Radiation Hardened Electronics Oversight Council will recommend an approach to minimize acquisition system barriers to support of system common objectives such as the P&Q investment.

[Whereupon, at 5:30 p.m., the hearing was adjourned.]

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